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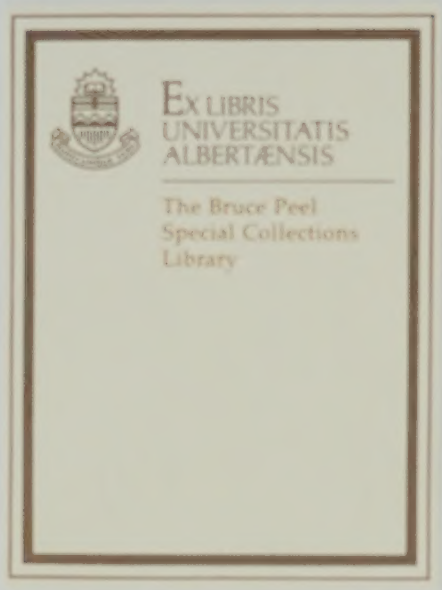
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THE UNIVERSITY OF ALBERTA

Teacher Awareness of Student Alternate Conceptions in Force and Gravity

By

Terrance Berg

A Thesis
Submitted to the Faculty of Graduate Studies and Research in Partial
Fulfillment of the Requirements For the Degree of Master of Education

Department of Secondary Education

Edmonton Alberta

Spring 1989

THE UNIVERSITY OF ALBERTA

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Teacher Awareness of Student Alternate Conceptions in Force and Gravity, submitted by Terrance Berg in partial fulfilment of the requirements for the Degree of Master of Education.

ABSTRACT

Twenty high school physics teachers were interviewed to determine their awareness of student alternate conceptions in the areas of force and gravity and the teaching strategies they use to deal with these alternate conceptions. The teachers responses were compared to alternate conceptions held by 315 grade nine students from feeder schools and the published findings on the four questions asked.

Edmonton students were found to possess nearly every alternate conception identified in previous research, in relatively similar proportions. A few undocumented alternate conceptions were also identified. At times, students were observed to arrive at the correct conclusion by using alternate conceptions.

The high school physics teachers, as a group, identified nearly all the alternate conceptions used by the students. However, individual teachers were generally aware of only a few alternate conceptions, with fully one third of the them possessing alternate conceptions themselves. The teachers were also unable to predict with any accuracy the different types of responses the students would choose or the proportion of students choosing each. The teaching strategies outlined by the teachers would be considered only partially effective according to current research findings.

This study clearly demonstrates a need for inservicing directed at high school physics teachers aimed at providing them with an awareness of student alternate conceptions and of potentially effective teaching strategies to deal with them. Also illuminated was a need for modification of teacher education at the university level.

ACKNOWLEDGEMENTS

My sincere thanks go to my advisor, Dr Wytze Brouwer for his continued encouragement and advice.

Gratitude is also expressed to Dr Heidi Kass and Dr Ernie Skakoon for their assistance and valuable suggestions.

I would like to extend my appreciation to the many teachers whose contributions were crucial to the success of this study, in particular the twenty six who volunteered to be interviewed.

I also wish to express my dearest thanks to my wife, Shannon and to my children Karl, Kyra and Mark for their patience and continued love.

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CHAPTER 1

The Problem

Introduction

In recent years, there has been a great deal of attention paid to student alternate conceptions of scientific phenomena. These alternate conceptions have been described by different researchers as misconceptions, pre-conceptions, alternate frameworks and children's science (Gilbert and Watts, 1983). The results from various studies have shown that students have concepts of the natural world that are quite different from those of our scientists. Since science education has been structured around the scientists' concepts (Kuhn, 1970) the implications of such findings could prove to be revolutionary. The 'Tabula Rasa' conception of the learner has come to be replaced with a concept of a learner who brings to class a complicated body of personal knowledge and understanding (Ausubel, 1968; Pope and Gilbert, 1983; Driver, 1981; Erickson, 1979; Osborne and Gilbert, 1980).

The teacher must, therefore be aware of different student alternate conceptions and be familiar with student explanations of natural phenomena and how students can gain incorrect conceptions from instruction. (Watts, 1983; Stepans, Beiswenger and Dyche, 1986) Examples used to illustrate one concept during instruction may convey a totally different meaning to the student, leading the actual outcome to be different from the intended (Anderson, 1986). For example, a common student misconception that gravity exists only inside a planetary

atmosphere (Gunstone and White, 1981; Watts 1982) could dramatically affect student understanding of a teacher's example of the apparent weightlessness of objects in an earth orbit, or of astronauts standing on a body not massive enough to hold an atmosphere.

Central to the majority of research involving student alternate conceptions is a belief that they are useful to teachers of science. A number of the earlier published papers felt it important to quote:

> "Ascertain what is known and teach accordingly."
>
> (Ausubel, 1968)

Respected researchers worldwide have completed intense research about what the students know and believe, (Gilbert and Watts, 1983; McDermott, 1984). More recently, researchers have tried to construct instructional activities designed to eliminate false conceptions and prevent future misconceptions. (Minstrell, 1982; Hart, 1987; Shuell, 1987) Researchers have studied populations covering the spectrum from child to adult and from student to teacher. (Arons, 1981; Champagne, Gunstone and Klopfer 1983) Alternate conceptions have been found in all age samples and have proved to be very resistant to change. Often, misconceptions held by older people are just sophisticated versions of the earlier alternate conceptions. (Stepans, Beiswenger and Dyche, 1986; Clough, Driver and Wood Robinson, 1987) However, little research seems to be available dealing with teacher awareness of student alternate conceptions, in spite of the fact that teachers' awareness (and subsequent usage) of this information is an acclaimed purpose of the research.

Purpose of the Study

The purpose of this study is to explore teacher awareness of students' alternate conceptions and teaching strategies used to instruct these conceptual areas.

Specifically, this study attempts to investigate the following questions:

Research Question #1: Do the Edmonton high school entry level students hold the same alternate conceptions that have been identified in previous research in the areas of force and gravity?

Research Question #2: Are senior high school teachers of physics aware of student alternate conceptions in the conceptual areas of force and gravity?

Research Question #3: Do senior high school teachers of physics have teaching strategies to deal with student alternate conceptions, in the areas of force and gravity, that would be considered effective according to current research? If so, what are their teaching strategies?

Significance of the Study

That there is a need for a study of teacher awareness of student alternate conceptions is a logical inference to be derived from the alternate conception research to date. Studies show that large numbers of students hold alternate conceptions and these must certainly impair

the students abilities to learn physics. (Maloney, 1985) This research may provide one explanation for the large numbers of students who consider physics difficult to comprehend.

Since the acclaimed purpose of alternate conception research is for teachers to use this body of knowledge to enhance their teaching, it is logical to identify what the teachers already know. How much of the research uncovered so far was already suspected by the teachers? What teaching strategies do these teachers consider to be successful in dealing with alternate conceptions? Do the teachers themselves possess and pass on misconceptions to their students? These are crucial questions to be asked of our teachers and there is no better place to ask them than in the locality of a major university that has been studying this field for a number of years, as one might assume these teachers to have had greater opportunity to be aware of research findings. Researchers must ascertain the degree of familiarity of teachers with student alternate conceptions, in order to plan for the instruction of future teachers and the inservice needs of current teachers. Writers of textbooks and teacher manuals must be aware of the alternate conception knowledge held by teachers to identify potential trouble areas that are not widely dealt with by the teachers.

Definitions

alternate conceptions - are personal theories and hypotheses held by individuals that are different from the currently taught scientific conceptions.

alternate frameworks - refer to the personal paradigms held by students that oppose or fail to fit the currently taught scientific paradigms.

conception - the personal theories and hypotheses of individuals (Gilbert and Watts 1983)

force - is the attraction or repulsion acting on a body. It is a vector quantity (has both magnitude and direction).

gravity - is the attraction between any two bodies in the universe. It is a vector quantity that has both magnitude and direction.

impetus - is a medieval concept of a force that is given to a body that enables the body to move. A body continues in this motion until this force is exhausted.

misconceptions - are personal theories and hypotheses that are acquired during instruction that oppose or fail to fit the currently taught scientific conceptions.

paradigm - refers to the set of concepts and beliefs that are shared by scientists about the nature of the world.

preconceptions - are personal theories and hypotheses held by students prior to formal instruction about currently held scientific conceptions.

Delimitations

In conducting this study, its scope was arbitrarily narrowed to studying physics teachers and students from the city of Edmonton,

Alberta. Specifically, this study involved only current senior high school teachers of physics (from public, Catholic and private schools), and end of grade nine junior high school students from feeder schools to the high schools employing the above teachers.

These teachers were queried only about their perceptions of student alternate conceptions concerning force and gravity, as these conceptual areas were among the earliest to be studied and thus assumed to be most available to teachers. The teachers were asked to limit their predictions to only those students who were entering physics 10 (approximate ages of 14 - 15 years).

Limitations

In considering the limitations of this study, teacher responses may have been influenced by their inhibitions if they perceived questions to be threatening and also by interviewer bias.

There is a possibility that teacher responses might have been misunderstood when interpretting transcriptions. Likewise, student results were dependent upon the students' correct interpretation of the questions, and upon the researcher's proper interpretation of their answers during analysis.

As it was not feasible to re-interview teachers (as some teachers indicated that they would ask the questions used in the study of their students the next time they were in the classroom) reliabilty might be subject to question. Students were likewise not retested.

Summary

The present study investigated high school teachers' awareness of the different alternate conceptions held by students and how prevalent the teachers expected them to be. Teachers were also asked what the sources for these alternate conceptions might be along with teaching strategies they would use to teach the conceptual areas addressed.

The results will be useful in designing and evaluating the instruction provided by Professors charged with the responsibility of teaching our future teachers. It will also illuminate ways of enhancing the instruction of current teachers.

CHAPTER 2

Review of the Literature

General History

Increasingly, it has been believed by education researchers that learning results from what is experienced, and the integration of learned concepts with a student's conceptual structure. The origin of such a line of thought is not a recent one and can be traced to the work of the early Gestalt psychologists (Posner, Strike, Hewson and Gertzog 1982). It is generally held, however, that the early work of Piaget was responsible for focusing educator's attention on the conceptions held by young children (Osborne and Wittrock 1983; Posner, Strike, Hewson and Gertzog 1982).

In 1968, Ausubel indicated that it was important to consider the knowledge that children had of the world around them and their conceptions as to how everything 'worked'. These conceptions were termed preconceptions and Ausubel believed they would be different from "proper" scientific conceptions. Ausubel (1970; as quoted by Preece (1984)) further stated that they would be "amazingly tenacious and resistant to extinction" and that "unlearning of preconceptions might well prove to be the most determinative single factor in the acquisition and retention of subject matter knowledge" (Ausubel 1968; Driver 1981).

From these roots, during the early 1970's there emerged world-wide "strong interest in research into content- and context-dependent learning in science" (Gilbert and Watts 1983). This interest has

expanded from papers and theses to conferences and major funded research groups. However, no coherence of the research from this common interest has yet been developed (Gilbert and Watts 1983). Thus, one encounters various descriptors within this research such as: 'children's science (Osborne, Bell and Gilbert 1983), 'alternate frameworks' (Driver 1981; Hallden 1983), 'conceptual frameworks (Driver and Erickson 1983), 'prior knowledge' (Finley 1985), 'natural thinking' (Guidoni 1985), 'preconceptions' (Clement 1982), 'misconceptions' (Helm 1980; Ivowi 1984) and 'alternate conceptions' (Driver and Eastley 1978). In spite of this apparent disunity, all these researchers are concerned with student conceptions in science before, during and after instruction.

Alternate Conception Studies Regarding the Concept of Force

Alternate conception studies regarding the force concept were among the first to be carried out. Raven (1967-8) noticed that in his study of 160 primary school children, students used the terms "push" and "pull" to refer to either a force (when used as verbs) or momentum (when used as nouns). Raven also noticed that these children had a natural understanding about momentum and its conservation law even though momentum and the momentum equation ($P = mv$) had no meaning to them.

Johnstone and Mughol (1976) conducted a survey of students in Glasgow from pre-O-grade to first year university, exploring their understanding of some 23 different physics concepts. The survey of these students demonstrated that they had great difficulty distinguishing between mass and weight, with the concept of pressure and

the idea of uniform motion (where an object can move with some constant motion without any force exerted on it to keep it moving).

Leboutet-Barrell (1976) observed that in more than 500 students (from 11 - 16 years of age), terms such as speed, force and power were used with little correlation in meaning with the scientific terms. Around the ages of 14-15 years, Leboutet-Barrell observed an increase in scientific vocabulary, and there was a movement away from defining these terms according to their usefulness to humanity. Instead students began defining terms in relation to nature.

McCloskey, Caramazza and Green (1980) studied a group of 50 students enrolled in undergraduate courses at John Hopkins University, Maryland and found that students, both before and after taking university level physics courses, believed there could be curvilinear motion in the absence of external forces. The sample consisted of students with a range of physics experience, from 49% of students having no formal instruction in physics to 14% of the students having completed a university level physics course. McCloskey, Caramazza and Green also noticed similarities between student responses and the medieval theory of impetus.

Champagne, Klopfer and Anderson (1980) tested 110 first year university students in order to study the correlation between conceptual understanding and achievement in Newtonian mechanics. These researchers observed that, as expected, students entered instruction with "a poor grasp of the major concepts of Newtonian mechanics." However, it was shown that these students had extensive and interrelated ideas about motion (preconceptions). In direct reference to the Kuhnian theory of

scientific revolutions (1970), Champagne, Klopfer and Anderson suggest that students might find great difficulty in rejecting their personal conceptions in order to accept the Newtonian concepts taught in school.

Arons (1981) used a Socratic dialogue approach to ask a number of University of Washington students probing questions about force and other concepts. From these dialogues he observed student difficulties stemming from their concept of an "instant", which they took to be a short but finite amount of time. This was interpreted to be one source of difficulty with student understanding of instantaneous velocity. Arons also observed a failure of students to interpret correctly Newton's Laws on Forces; in identifying the forces acting on interacting particles (Newton's 3rd) and computing the resultant for each of the individual particles (Newton's 2nd).

Clement (1982) did a study of first year engineering and physics students at the University of Massachusetts. In this study Clement discovered that over 80% of these students, prior to university instruction in physics, held the preconception that motion implies a force. (Viennot (1979) assumed such a preconception in analyzing results from a study of students in their last year of high school and first two years of university.) In a small sample of these students that were interviewed, references by the students to "force of the throw", "upward original force", the "force up from the velocity" and "the force up from throwing the coin up" were made.

Osborne (1982), in investigating the word force, interviewed some 40-50 children to determine whether they believed that force existed in some 20 different situations. In this enterprise, Osborne found that

many children held the belief that "a moving object must have a force within it in the direction of motion." Observing the same concept held by students with two years of university physics, Osborne did a comprehensive study on students from ages 13 to 17 years (sample sizes ranged from 13 year olds (N = 254) to 17 years olds (N = 75)). His results showed that from 46% to 66% of these students shared this concept (see Table I (Page 28) for the complete numerical data on all groups and their choices).

Champagne, Gunstone and Klopfer (1983) proposed that the source of these alternate conceptions (which they chose to call naive conceptions) stems from years of observation of motion in which friction is present, while the eye is too insensitive to notice the accelerations present. These authors believe that four rules can account for the basis of these alternate conceptions in forces and motion. These are:

a. Force, when applied to an object, will produce motion.

b. Under the influence of a constant force, objects move with a constant velocity.

c. The magnitude of the velocity is proportional to the magnitude of the force, so that any increase in velocity is due to increasing forces.

d. In the absence of forces, objects are either at rest, or if they are moving, they are slowing down."

These authors also found instances where students would retain alternate frameworks in certain contexts while apparently rejecting them in other contexts. For example, students would say that heavy objects and light objects in free fall would fall at the same rate, while believing that heavy objects would slide down an inclined plane faster than light objects. (Maloney (1985) conducted a study on Creighton University

students in where he inferred that the majority believed that heavier objects fall faster).

Watts (1983), using the Interview About Instance approach (Osborne and Gilbert 1980; Gilbert, Watts and Osborne 1982) interviewed 12 students ages 11 to 18 years about their interpretations of examples and non-examples of forces. Watts observed eight distinct frameworks (as used by at least two different students) involving forces. These are as follows:

> "a. Forces are obligations to complete an action against some resistance.
>
> b. Objects restrained in a position have force.
>
> c. Forces are designated to those objects that are causing or will cause events to occur.
>
> d. When two or more forces come together they can combine to change the movement of an object.
>
> e. Moving objects are a force, which is made manifest when the objects collide with some other body.
>
> f. If a body is moving there is a force acting upon it in the direction of the movement. If a body is not moving there is no force acting upon it.
>
> g. Force is an action. The amount of force is proportional to the amount of activity taking place.
>
> h. Forces are positive actions that are effective when they come into contact with objects."

Watts and Gilbert (1983) conducted a study with seven students aged 15 to 17 years using the Interview About Instance approach (Osborne and Gilbert 1980; Gilbert, Watts and Osborne 1982). These researchers discovered from their students that three different relations between force and energy were held. Some of the students believed the concepts of force and energy to be synonymous and interchangeable. Other

students maintained a belief that there is some connection between force and energy, while others believed them to be separate and unrelated.

Alternate Conception Studies Regarding the Concept of Gravitation

In one of the earlier studies of children's conceptions of the earth, Nussbaum and Novak (1976) encountered five different conceptions of the earth. Of these conceptions, the fourth identified a notion of objects in free-fall falling at some direction angled away from the earth's center. This implies that some children may not consider the directions up and down in relation to the earth's center. A later study by Nussbaum (1979) expanded his notion four to state that for objects on the earth's surface down pointed towards the ground (and thus the earth center), whilst inside the earth, "down" pointed to the "bottom" of the planet (the south pole). This was further supported in a study by Nussbaum and Sharoni-Dagan (1983)).

Gunstone and White (1981) studied first year students (N = 175 to 466) at Monash University in Australia about their understanding of eight physical situations, all involving some aspect of gravity. These researchers encountered a couple of alternate conceptions violating Newton's Third Law, i.e. a book supporting an eraser would not be exerting any force on the eraser, and the force exerted by an eraser on a book would not be equal to the force exerted in return by the book. Gunstone and White also observed that students were greatly overestimating the decrease (or diminishing effect) of gravity as the distance from the earth's center increased.

Watts (1982) conducted a study on 20 students from the ages of 12 to 17 years. Using the Interview About Instance approach (Osborne and Gilbert 1980; Gilbert, Watts and Osborne 1982), Watts identified a number of gravitational conceptual frameworks held by children. These are as follows:

> "a. Gravity is a force that requires a medium to act through.
>
> b. Where there's no air, there's no gravity.
>
> c. Gravity increases with height.
>
> d. Gravity is constant - moving objects try and fail, to 'counteract' gravity.
>
> e. Gravity begins to operate when objects start to fall down and continues until they are at rest on the ground.
>
> f. Gravity is a large force.
>
> g. Gravity is selective - it does not act on all things in the same way, nor on the same things in the same way at all times.
>
> h. Gravity is not weight - but can act in conjunction with weight to hold things down."

Watts also found evidence that some students considered gravity to be power while others thought it to be a form of energy.

Sneider and Pulos (1983) conducted an extensive study using California children aged 9 to 14 years based on the Nussbaum and Novak study in (1976). This study supported previous research and found that 23% of the 13 year olds and 11% of the 14 year olds held the notion that objects inside the earth would fall down to the south pole.

Ruggiero, Minzoni, Cartelli, Alighieri, Dupre and Vicentini-Missoni (1985) studied the relationships of weight, gravity and air held by

students from the ages of 12 to 13 years. These researchers discovered and supported the following alternate conceptions:

"a. Air pressure is the cause of gravity and weight.

b. Gravity acts on the weight of objects.

c. Weight is a property of objects.

d. Objects fall because of Natural Motion."

Alternate Conception Studies Involving Teachers

Some of the earlier studies conducted on teachers are those of Miller (1962) and Schmidt (1967). In these studies teachers were found to have less understanding of science than some of their students. The worst of these findings indicated that 38% of the "high ability" students in grades 11 and 12 scored above half of their teachers on a TOUS exam (Test on Understanding Science) and 68% of these students scored better than a quarter of the teachers (Miller, 1962 as quoted in Schmidt (1967)). Schmidt (1967) in repeating the same study as Miller, also found that some of the teachers understood less of science than their students did.

Lederman and Druger (1985) reported that as a result of the works of Miller (1962) and Schmidt (1967) "much time and effort has been invested (with little success) to promote more adequate teacher conceptions of science ...".

Arons (1981) found a number misconceptions to be "widely prevalent among all our secondary school teachers" (Arons page 170). Although no statistics are mentioned as to the universality or prevalence of these

misconceptions, Arons states them to be no different than those held by US college and high school students.

Osborne (1982) found from a survey done on primary teacher trainees (N = 34) and experienced primary teachers (N = 53), that up to a third of them held a number of misconceptions about what classifies as an animal.

Studies About the Teacher Awareness of Student Alternate Conceptions

To date, there appear to be very few studies published that mention teacher awareness of student alternate conceptions.

Watts and Zylbersztajn (1981) found British teachers (in a small study of 5 teachers and their students) to be generally aware of student alternate conceptions of force and motion, and action-reaction force and motion. However these teachers were found to be generally unaware of student-held conceptions regarding weight and distances above the ground or force and gravity (Watts and Zylbersztajn wrote: "but their predictions were not very good in the others").

Osborne, Bell and Gilbert (1983) believe that secondary school science teachers "are largely unaware of children's science and are frequently not sensitive to the viewpoints children bring with them to science lessons." Two other researchers, Anderson and Smith (1985) found fifth grade science teachers to be unaware of student-held alternate conceptions of light and biological organisms.

Implications for Teachers

Ausubel's statement "Ascertain what is known and teach accordingly" has been echoed by a host of researchers through their belief that it is important for teachers and curriculum developers to be aware of student alternate conceptions (Zarour, 1975; Osborne and Gilbert, 1980; Arons, 1981; Watts and Zylbersztajn, 1981; Gilbert, Osborne and Fensham, 1982; Watts 1983; Aguirre and Erickson, 1984; Gardner 1984; Finley, 1985; Zietsman and Hewson 1986, Aguirre, 1988). Fensham (1980) believes that science curriculum developers have either ignored or inadequately considered student alternate conceptions. It is further considered important for teachers to be aware of student meanings for words and concepts so that instruction will be interpreted correctly (Watts, 1982; Watts and Gilbert, 1983; Osborne and Wittrock, 1983; Fensham 1983). Hallden (1983) and Champagne, Klopfer and Anderson (1980) have stated the alternate conceptions held by students can make tasks assigned by teachers meaningless to the extent they interfere with learning. Osborne (1981) believes that unless teachers identify student alternate conceptions and design their instruction accordingly, "some of the childrens' ideas will not change or will change in unanticipated ways." Strike and Posner (1982) consider it important that techniques be developed for teachers to become aware of student alternate conceptions.

Chapter 3

The Tasks

Introduction

Five different questions were originally selected for this study, two of which were based on physical situations on earth and the remaining three physically situated in space. Two questions (one on the earth and the other out in space orbiting the earth) dealt with student predictions of objects that are moving in a circular path or orbit. Two questions (one on the earth and the other on the surface of the moon) dealt with gravity and motion. The other question (which was later withdrawn because it was felt to be outside the scope of a grade 10 Physics class) dealt with two dimensional motion from an initial sideways drifting rocket that fired engines tangential to the original direction of drifting.

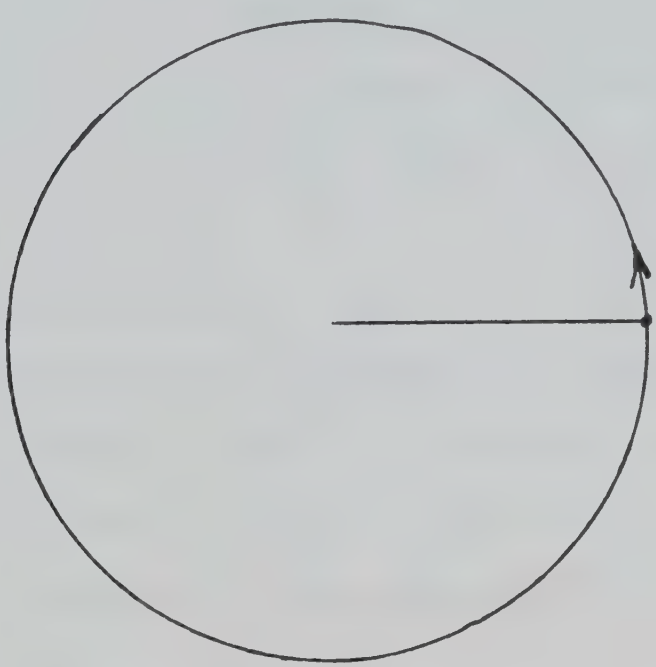
Question #1

The first question (Figure I) was drawn from a study originally done at John Hopkins University on 50 students enrolled in undergraduate courses (McCloskey, Caramazza and Green, 1980) (Gardner, 1984 in a later study describes these students as freshman physics students). Of these 50 students, there were three spoiled responses. Of the remainder, 15 students had no prior physics instruction, 22 had one high school physics course and ten had completed at least one college physics course.

Figure I

Question #1

Imagine that someone has a metal ball attached to a string and is twirling it at high speed in a circle above his head. In this diagram you are looking down on the ball. The circle shows the path followed by the ball and the arrows show the direction in which it is moving. The line from the center of the circle to the ball is the string. Assume that when the ball is at the point shown in the diagram, the string breaks where it is attached to the ball. Draw the path the ball will follow after the string breaks. Ignore air resistance.



McCloskey et al (1980) found from these students that 53% of the students predicted a tangential path, 30% predicted a curvilinear path, 6% believed the ball would travel radially straight outwards and 6% thought the ball would travel straight outwards between the tangential and radially out directions.

The dominant alternate conception, that of the 30% choosing a curvilinear path, had most of the students drawing a curved path that gradually straightened. These students believed that an object that is forced in a curved path will receive a "force" or "circular momentum" that results in the object continuing to travel in that curved path. Eventually the "force" or "momentum" dissipates allowing the object to eventually travel in a straight path.

The students declaring that the ball will travel radially straight outwards had a concept of a centrifugal force pulling the ball straight outwards. The string in this instance, was preventing the ball from flying outward as the centrifugal force was attempting to force it or move it. Once the string's restraint on the object was removed, the ball travelled straight out.

The remaining 6% of the students believing the ball would travel in a straight line somewhere between the tangential and radially outwards considered the trajectory to be a result of the centrifugal force pulling the ball outwards and the velocity of the object at release point.

Gunstone (1984) ran a study on 68 Year-10 students drawn from a Catholic Girls' School and a state high school in order to clarify some pre-instructional alternate "frameworks" about circular motion.

Specifically Gunstone was looking at the extent of three different concepts motion implies a force, impetus theory and a belief in centrifugal force.

Unfortunately, Gunstone's sample contained ten students who had been given a special unit on forces and motion that was based on preconception research. Furthermore, a number of students did not finish all the questions and others misinterpreted some of the questions.

One of the questions chosen by Gunstone was almost identical to that used in the John Hopkins University study. It involved having the students draw the path of a ball that has just left a curved pipe. Gunstone used two pipes, one curved 90 degrees and the other 250 degrees. (McCloskey, Caramazza and Green had used two pipes, one curved about 250 degrees and the other about 610 degrees (one full loop plus another 250 degrees)).

McCloskey, Caramazza and Green had found that 33% of the students drew a curvilinear path for the less curved pipe (250 degrees) and 51% drew a curvilinear path for the greater curve (610 degrees). Gunstone found that 15% drew a curvilinear path for the lesser curve (90 degrees) and 47% drew a curvilinear path for the larger pipe (250 degrees). For the section of each question which was similar (250 degree curve), about one half the younger students drew the curved path, whereas one third of the university students drew the curved path. Gunstone's work supports the results of the John Hopkins University study in that the students invoked similar reasonings (circular impetus) to support their prediction.

Both these studies showed that students percieve that a greater circular impetus is given to an object by forcing it to travel through paths of increased curvature. Neither study addressed the student perception of the spin given to an object resulting from it's motion on a curved path, and the result of such a spin if the object is suddenly freed.

Gunstone also found that 84% of his sample espoused the belief that motion implies a force. This number is in the 80% range, which is supported by a number of research findings. (Osborne, 1980; McCloskey, Caramazza and Green, 1980; Viennot, 1979; Gunstone, 1984 and Gardner, 1984).

Gunstone found a very small proportion of his subjects to use centrifugal force as an explanation; only 12% of the students were clearly recorded as using it. Gunstone however, expressed uncertainty about these findings as the study did not proceed as he intended and there was circumstantial evidence that these numbers might be higher. One should note that a total of 12% in the university study used a concept of centrifugal force in predicting a path for the flight of an object swung in a circle and released.

The results of the Edmonton grade nine survey (N = 315) for this first question are discussed in Chapter five, pages 48 to 61 with the teachers' predictions of the students responses discussed in pages 61 to 71.

Question #2

Question #2 (Figure II) showed a ball being thrown into the air. Students were then asked in which direction the net force was acting on the ball when the ball was moving upwards, at the top of its trajectory and when the ball is falling back down.

This question was one of the earlier mechanics questions to be used with students in preconception research (Clement, 1982; Watts & Zylbersztajn, 1981; Arons, 1981 and Osborne, 1982). These studies looked at student populations from the equivalent of junior high school to university level. Common to all was the finding of a 'force implies a motion' belief held by over half the students of all ages.

Watts & Zylbersztajn (1981) studied 125 (end of the third year) 14-year-olds attending four comprehensive schools in Reading and London. In this study they found that 85% of students associated force with motion. These researchers found that students perceived the stone to have a force upward, away from the person's hand, as the stone moved upward after being thrown. About half of these students believed the stone to stop at its maximum height before reversing its direction and falling back down (Thus no force was expected to act on the object at the top). Others perceived there to be no stoppage, only a reversal of the stone's movement.

Watts & Zylbersztajn found that a "considerable number of the children" related the amount of motion to force, implying that students held a concept of force similar to what physicists call momentum.

Gravity was seen by some students to be present throughout the entire stone's motion, whereas others considered it to "switch on" at

Figure II

Question #2

A person throws a tennis ball straight up into the air just a small way.

The questions are about the total force on the ball.

If the ball is on the way up, then the force on the ball is shown by which arrow?

If the ball is just at the top of its flight, then the force is shown by which arrow?

If the ball is on the way down, then the force on the ball is shown by which arrow?

the top or on the way down. For a few students, gravity was more related to the phenomenon of falling rather than being seen as a force, with a minority of students holding the Aristotelian notion of the earth attracting matter (Natural Motion).

John Clement (1982) studied 150 first year engineering students at University of Massachusetts. These students had not had college physics but most had high school physics. He found, upon asking these students the direction of a force acting on an object thrown upwards that 88% gave an incorrect answer, 90% of incorrect responses had arrows showing an upward force. Out of the entire group of students, 11 were interviewed, of which 8 incorrectly answered the question. Seven of these 8 students mentioned that some force was in the direction of the motion. One student was classified as questionable because of his/her mention of a "momentum force"

Arons in 1981 described the results of "Platonic" discussions about the motion of a ball at the highest point. One finding is a misconception that develops from misinstruction. The student perception of no force acting on an object at the highest point in its flight can be traced to teachers and texts mentioning that the object comes to a complete stop for an instant, which is interpreted by the students to be some finite time interval. Thus, when this concept is used with the equation of acceleration where:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{some time interval}}$$

the acceleration must equal zero. Since this would be a learned misconception, one might expect to see it increase with the level of education among students.

Roger Osborne published the results (Table 1) of a detailed study (1982) of 845 students varying in ages from 13 to 17 years. In this study, he found and presented numerical evidence supporting a number of the alternate conceptions found by other researchers.

The most prevalent conception found to be held by students in Osborne's study was that a "motion implies a force". Sixty six percent of the 15 year old students were found to hold this conception. This percentage was the highest for all age groups surveyed, but the average was around 54% for students aged 13 to 17 years.

Another stable conception for students at different ages was that the force was in the opposite direction to the object's motion. Thus, as the object moved upwards the force was perceived to be directed down, with no force at the highest point where the object stops, and upwards as the object fell to the earth. Osborne found 10% of the 15 year old students to hold such a conception with an average of 9% of all students over all ages.

The number of students giving the correct response to this question (the force acting on the object was directed downwards throughout the object's entire motion) was found to jump dramatically between the ages of 15 and 16 years. One would assume this to be a result of instruction in the schools. Prior to 16 years of age, Osborne found an average of a little over 7% believing that the force acting on an object was directed

Table I

Osborne's Results (1982) from Question #2

Groups of Choices Picked	13y (N=254)	14y (N=195)	15y (N=174)	16y (N=147)	17y (N=75)
bca	46%	53%	66%	53%	52%
aaa	5%	11%	6%	22%	19%
baa	14%	11%	9%	4%	1%
aca	9%	5%	5%	14%	21%
acb	11%	10%	10%	7%	7%
other	11%	9%	3%	0%	0%

Code for letters

bca ... Force is upwards (on way up), No force (at top), Force is downwards (on way down).

aaa ... Force is downwards through the entire motion.

baa ... Force is upwards (on way up), Force is downwards (at the top and on the way down).

aca ... Force is downwards (on way up and on way down), No force (at top).

acb ... Force is downwards (on way up), No force (at top) Force is upwards (on way down).

downwards throughout the motion; this number reached a little over 20% from 16 years on.

The misconception discussed by Arons (1981), where the object was thought to stop for a finite amount of time at the top thus implying the net force at this point to be zero, was also supported by this study. On average a little over 6% of students from ages 13 to 15 years were found to hold this conception. At age 16 years this number jumped to 14% and at 17 years the number climbed further to 21%. Support for Aron's claim stems from the belief that instruction in physics starts between the ages of 15 and 16 years (as suspected from the parallel increase in the numbers of students holding the correct answer). One would also assume that as students mature such a "learned" misconception would be held by more.

The second most common alternate conception held by the 13 year olds appears to be the notion that no force acts on the object until the top of the flight path, where gravity kicks in (Watts & Zylbersztajn, 1981). After this point the force is perceived to be directed downwards for the remainder of the flight. Nine percent of the 15 year olds were found to hold such an alternate conception. This number was found to dwindle to 1% by 17 years of age.

The results of the Edmonton grade nine survey (N = 315) for question #2 are discussed in Chapter five, pages 72 to 81 with the teachers predictions of the students responses discussed in pages 81 to 90.

Question #3

This question was chosen from Lambert's unpublished Master's thesis (1981) in which she studied 40 grade 10 physics students (14 -15 years old) from the Edmonton Public School system for their alternate conceptions about inertia and the effect of forces on an objects motion.

In this question, students were shown a globe and a model of a spacecraft with an astronaut. The spacecraft with the astronaut inside was shown to the students in a polar orbit around the earth. Students were asked what would be the position of the astronaut if he/she had left the spacecraft (moving north) at the equator, when the spacecraft had orbited to a position over the north pole.

Lambert classified her student responses according to two parameters; orbital velocity of the astronaut and the displacement of the astronaut with respect to the spacecraft. The most common student responses are shown in Table 2. One student response was unclassifiable under Lamberts framework: the astronaut was believed to move in the reverse direction of the spacecraft.

Lambert found a number of alternate conceptions to be held by these students;

1. No gravity exists where the astronaut is because he/she is weightless.

2. No gravity exists where there is no atmosphere.

3. Gravity is selective in that it only acts on the spacecraft.

4. Gravity is used as a "force forwards" and as such fits into the force implies a motion concept.

Figure III

Question #3

A globe of the earth and models of a spaceship and a spaceman were presented. The spaceship with the spaceman inside was shown orbiting the earth in a path over the north and south poles. The student was then asked "If the spaceman goes outside the spaceship to make repairs without a lifeline and then let go when the spaceship was over the equator (moving north) where will he be when the spaceship is over the north pole?"

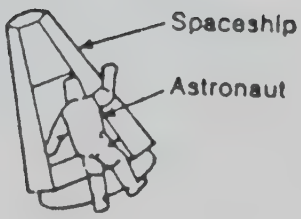


Table II

Lambert's Results (1981) from Question #3

Student Response	Edmonton Grade 10 Physics Student (1981)
Stays with Spacecraft	27.5% (N = 11)
Falls Behind in Orbit	22.5% (N = 9)
Remains at Equator	32.5% (N = 13)
Falls toward Earth	10.0% (N = 4)
Drifts Outwards from the Earth	5.0% (N = 2)
Other Responses	2.5% (N = 1)
Total Responses	(N = 40)

Lambert also found some students to justify the fact that the astronaut could remain stationary over the earth in terms of the earth and moon (or sun) not falling towards each other. Some explained this as a "balancing of gravitational forces".

The results of the Edmonton grade nine survey (N = 315) for question #3 are discussed in Chapter five, pages 92 to 102 with the teachers predictions of the students responses discussed in pages 102 to 116.

Question #4

Question #4 (Figure IV) was selected from the Watts & Zylbersztajn study (1981) and was designed to explore student concepts of force and gravity as identified from two other studies (Watts, 1982 and Osborne and Gilbert, 1980).

The question shows an astronaut standing on the moon, holding a wrench off to one side. The astronaut is described as gently releasing the wrench and is shown to do so. The student is then asked what the direction of the force acting on the wrench is.

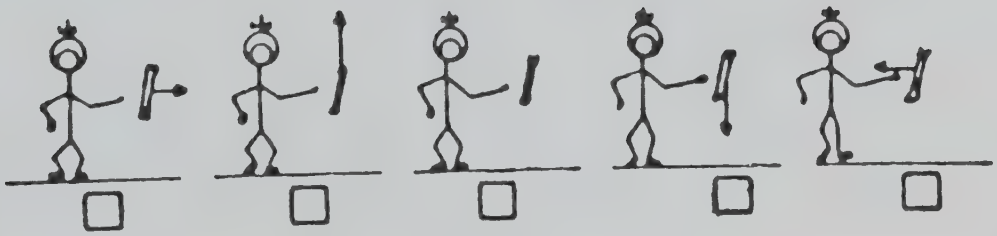
Watts and Zylbersztajn studied 125 (end of the third year) 14-year-olds attending four comprehensive schools in Reading and London. The authors found that almost 80% of the student answers came from two choices: either the wrench would remain stationary at the position released or it would float upwards away from the lunar surface. Student reasoning focused on the fact that the moon had no atmosphere and thus had no gravity. Other responses from students indicated that

Figure IV

Question #4

Here is an astronaut on the moon. He has gently let go of his wrench. The arrows are supposed to show the direction of the force acting on the wrench. Which drawing do you think best shows the force acting on the wrench?

No Force



they thought there was no gravity on the moon and thus no force and a few mentioned the "moon's air" acted to force the wrench upwards.

Moorfoot (1983) conducted a study using 10 randomly selected students from ages 11 to 12 years and found much agreement with the Watts & Zylbersztajn study in that students show a strongly perceived link between gravity and atmosphere, and that objects would float upwards in the absence of gravity. These students generally felt that weightless objects would float upwards, with some believing them to continue until reaching outer space.

Moorfoot found that seven of the ten students believed that air was responsible for weight and gravity. These students felt everything had weight except air itself. Moorfoot felt that students seemed to believe two factors were responsible for the object's flotation; air and a lack of weight.

Ruggiero, Minzoni, Cartelli, Alighieri, Dupre and Vincentini-Missoni conducted two similar studies in 1985. The first involved 22 Italian middle school children of 12 - 13 years in age, followed by another 40 pupils (ages not given, but from the same school). These researchers were attempting to find the differences in the associations between weight, gravity and air pressure held by students. One of the questions used in this study was the same "Astronaut on the Moon" question used by Watts & Zylbersztajn, in order to explore the conceptions between atmosphere and gravity. Out of the 40 students surveyed, 55% felt the object would float and 5% felt it would fall due to the moon's gravity. The remaining 40% of the students felt the stone might fall due to natural motion, but were uncertain that

this natural motion exists on the moon, because air was felt to be necessary for natural motion to exist.

The results of the Edmonton grade nine survey (N = 315) for question #4 are discussed in Chapter five, pages 117 to 127 with the teachers predictions of the students responses discussed in pages 127 to 135.

CHAPTER 4

Methods and Procedures

The Teacher Pilot Study

The subjects used for the pilot study were four teachers, two of which had previously taught physics, and two being qualified and having the desire to teach physics. All four teachers were employed at the same school which was easily accessible to the interviewer. Only four teachers were approached for this pilot and all four volunteered without reservation.

The pilot was run in two sets at the end of December 1987. Two teachers were interviewed and the results were transcribed and discussed with advisors. Necessary changes were implimented prior to concluding the piilot.

Procedure

The teachers were placed at a desk or table of their choosing and a tape recorder was placed on the table and set to run.

At the beginning of the interview, the teachers were told that the purpose of the study was to gain information regarding the teacher's opinions and beliefs about what the most popular response of students would be when asked certain questions. Following this introduction the teachers were given the first question to read. After they had read the question, they were asked to list the different answers student would give and predict the percentage of students that would choose each of

the responses. These predictions were written beside or beneath each of the responses. Each of the questions was in turn completed in the same manner. Once the teachers had given their predicted student responses, they were asked if they could think of reasons why the students would choose the particular responses to each question. After all five questions had been completed, they were queried as to how they would deal with incorrect student responses.

Teachers were encouraged to feel relaxed and comfortable throughout the interview. The intent was not to be threatening to the teachers; rather to make sure they would answer questions freely, more fully and with as much honesty as possible. Thus, prior to and during the interview, they were made to feel that their answers were valuable in order to add to research and that they were helping a fellow colleague.

The length of time for each interview ranged from about 45 minutes to 1 hour and 15 minutes.

Treatment of Results

All interviews were recorded on a cassette tape recorder. These were transcribed in totality for the pilot interviews. The transcriptions were broken up into the answers for each of the five different questions and then analyzed.

Following the initial two teacher interviews, two more questions were added,. The first involved predicting the path of a projectile thrown from a cliff, and the second being the path of an object dropped from a moving source such as a running human, both as witnessed from a stationary frame of reference on earth.

In analysis, the predicted responses of the teachers were compared with the actual student responses of other researchers. Transcripts of the teacher interviews were read to determine teacher's understanding of the reasons why some students would choose the different responses.

Results of First Teacher Pilot

From the first pilot it became clear that the two experienced physics teachers were unaware of a number of student alternate conceptions. One teacher was found to possess a number of misconceptions herself. The other teacher, when told of the prevalence of these alternate conceptions, challenged me to run the test on one of his children, a student who had passed the high school physics program with averages above 90%. This teacher expressed emotions of disbelief and annoyance when his child gave the correct answer to only two of the five questions, expressing in the remaining three questions popular student alternate conceptions.

When these results were discussed, with advisors concern was expressed about the fact that three of the questions dealt with situations in outer space and that more terrestrial questions should be included. A number of suggestions were made to enhance and structure the interview process. The fact that one of the two teachers possessed misconceptions was unexpected, so a strategy was developed to pursue them in greater depth during future interviews. It involved asking the teacher to explain how they would teach a child who was having difficulty understanding the teachers correct answer, thereby, in a

round-about way, determining which answer the teacher thought to be correct.

Results of Second Teacher Pilot

The second pilot supported the findings of the first pilot, that the physics teachers appeared unaware of a number of student alternate conceptions. Both of these teachers had not previously taught physics, but were qualified and desiring to do so and both had tutored physics students for over two years. Misconceptions were found to be held by both of these teachers and they appeared to have few ideas on how to teach in the areas from which the questions were drawn.

The Student Pilot Study

The subjects used for the student pilot were 22 students, surveyed on the first day of physics 10 instruction in February 1988. Three students had been previously exposed to physics with the remaining 19 never having formal physics instruction. All of these students were enrolled in the interviewer's class and varied in ages from 16 to 28 years.

Procedure

The students were presented with the five questions used for the teacher interview in the first day of instruction in a physics 10 class. They were asked to clear their desks and were given a number of blank white sheets of paper. Each question was completed in the same order as

given to the teachers. The questions were read out to the class, and then a sketch was drawn on the chalkboard depicting the event. The question was then repeated and the students were asked to write their response down and explain the reasons for their answer. Any queries raised about the question itself were answered in order to make the question clearer to the student. Each question was completed before continuing to the next.

Treatment of the Results

Student responses were analyzed for the conception (stated or implied) used to answer the question. The responses of the students were compared to the results found by the original researchers and those predicted by the physics teachers. These responses were summed and placed on charts comparing them with the findings of educational researchers and with the physics teachers.

Results of the Student Pilot

The student pilot appeared to agree closely with the results of the educational researchers in all five questions but were quite different than the expected responses of the physics teachers. Students of a range of ages and of a number of nationalities (Canadian, Sicilian, Chinese, Ugandan, East Indian, Nicaraguan and others) were found to possess a number of alternate conceptions.

These results were found to be encouraging in that students were responding to questions similar to other students in previous studies.

The Main Teacher Study

The subjects used for the main study were twenty teachers currently teaching a high school physics course in the city of Edmonton. These teachers were employed in either a private, public or catholic school in the academic school year of 1987-88. These teachers were not randomly sampled, but were all on either the south or east side of Edmonton.

No teacher refused to participate in the study and every physics teacher from each school contacted volunteered. All teachers were interviewed during the latter half of January and throughout February 1988.

Procedure

All teachers were contacted through introductions from other teachers working in the school or through the science department head. A brief description of the research was presented to the teachers. Once this was completed an interview time was set up with each teacher. Every teacher except one was dealt with in the same manner and these teachers cooperated fully. One teacher failed to extend full cooperation for this study. Although he initially volunteered, he refused to predict the percentages of students choosing responses in some questions.

All teachers were interviewed at their place of employment in a room and time of their choosing. All interviews except one ran continuously from question #1 to #5. In one interview, the discussion

took longer than expected, resulting in the teacher having to return to teach. This interview was then completed the following day.

The interviews were based upon the original five questions run in the pilot study with some modifications. Teachers were asked to predict student responses to a question, explain the reasons why they felt students might make such a choice and then expound upon their teaching strategies when dealing with this subject matter. By dealing with each question thoroughly before going on to the next, interviews were enhanced by streamlining them. As the teachers became familiar with the structure of the interview, it allowed them to think about teaching strategies during the initial phases of each question.

The Interview

Once teachers were ready to be interviewed, a cassette tape recorder was placed on the table or someplace nearby to record the conversations. All five questions were now placed in front of the teachers and the following explanation of the procedure was provided:

> "What I have here are five questions dealing with mechanics that have been presented to students around the world, from junior high school to university. I want you to predict for each question what different student responses you feel you might get from physics 10 students if you were to give them this question on the first day of instruction. I would like you to draw each of the student responses on the question in front of you."

Once the teachers had indicated their responses, I then asked the teachers to predict the percentage of students that would choose each of the alternatives. I then asked the teachers to explain why they thought the students would choose the wrong responses. Six of the twenty teachers were found to possess one or more misconceptions (Appendices 1-4). In these cases, the teacher was asked how they would explain their correct answer to a student having difficulty understanding what these teachers perceived to be correct answer.

Once the first parts of the question were answered, teachers were asked how they would teach the concepts dealt with in the question. They were asked to describe specific strategies that should allow the student to understand the concepts.

At the end of the interview, some teachers had still not committed themselves to what they believed the correct answer would be for certain questions. Thus, a request was made to add the percentages of students they felt would get the correct answer after instruction. The request was worded such that the teachers wrote their estimate only beside their correct answer. In doing so the teachers were forced to identify the answer they perceived to be correct.

Comments on the Interview

Some difficulty was experienced in having the teachers predict the percentages of students answering each of the different responses. In some cases, ranges of percentages were initially expressed by the teachers, with an estimate finally being chosen somewhere near the

middle of the range. One teacher, however, refused in a number of instances to estimate percentages, stating they were irrelevant.

In some of the cases where the teachers did not know the answer to the question, there was difficulty getting the teacher to identify which answer they thought to be correct. Thus, their descriptions of why they felt the student would choose the wrong answers were very vague. Comments like "they just don't understand the concepts" were given. In a number of cases, it was evident that the teacher had never thought of using special teaching strategies before.

Treatment of Results

All interviews were recorded on a cassette tape recorder. These were transcribed for the responses of the teachers regarding each question. In a few cases the interview was transcribed in totality where it helped to clarify teachers responses or it was felt that the interviewer might have biased teacher responses.

Charts and tables summarizing teacher responses for all parts of each question were also prepared. These responses were compared to the data gathered from other studies including the student study completed in Edmonton.

The Main Student Study

The subjects used for the main student study were 315 grade nine science students in their last month of grade nine instruction. These

students were selected on the basis of attendance in a feeder school to one of the high schools where the physics teachers were surveyed.

The schools used in this survey were contacted through the department head of science in all cases except one, where the principal was contacted. Permission to survey the students was granted in all schools contacted except one, where the department head felt that external surveys and testings had already taken away too much of the school's instructional time.

Procedure

All science department heads and principals were contacted by telephone. A brief description of the research was given to these individuals, as well as a description of what was being asked of them. Once this was explained a time was given when the survey forms would be dropped off at the school. All the department heads and the principal cooperated fully, volunteering all students in their school for the study.

All surveys were given to the students by the teachers, at a time and setting of the teacher's choice. The teachers agreed not to discuss any of the questions with the students until all students at that school had been surveyed.

The teachers were instructed that they were only to answer questions that helped clarify the problem situation, to make sure the student understood the physical situation presented to them. There was no set time limit for the students to complete this survey. Instead the

teachers were requested to allow students enough time to answer all four questions. The expected time for this was between 15 and 30 minutes.

Comments on the Student Survey

There were few difficulties with this survey as structured. There were only a few response sheets spoiled by students not taking the survey seriously and almost every student wrote down at least some response to every question.

One teacher who ran the student survey on his grade nine students, indicated an awareness of other people doing similar research at the University of Alberta. Cursory examination of all grade nine student results indicated no differences in the numbers of alternate conceptions held by his students with respect to the others.

Treatment of Results

All student response sheets were numbered sequentially and coded to indicate the source school. The explanations written by the students supporting their answer were read to confirm that the students' diagrams represented the students' intended answers.

Student data were divided into three different groups for analysis; those intending to take physics at high school and those not planning to take physics and the combined group of students.

Charts and tables were made summarizing the student responses for all four questions. All data was compared to other research findings to indicate agreement or disagreement with the original studies.

Chapter 5

Analysis of the Tasks

Question #1

Edmonton Grade Nine Students Responses

Question #1 was drawn from a group of questions presented to a number of students at John Hopkins University in 1980. This question showed the top view of a ball attached to a string and rotated in a circle. The students were told that the string broke at a certain point (this was shown by the ball drawn at the breaking point with an arrow showing its motion in a circle) and were asked to draw in the path they expected the ball to travel.

Two types of responses were taken to be correct for the first question: tangential from break point and straight from the arrow drawn on the circular path (Figure 5). In the second case it was felt that the students cued on the arrow as representing the direction of ball's motion at that instant when released.

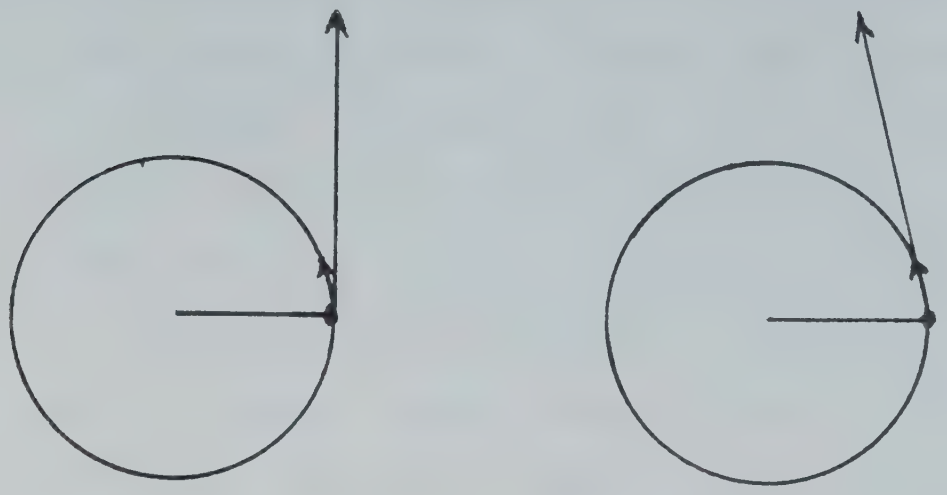
It was found (Table III) that 20.0% of the students on average chose the correct response. Student responses for the tangential path indicated that they considered the string acting as a restraint that forced the ball to move in a circular path. Once the string was removed students made numerous descriptions of the ball's inertia moving the ball forwards. Other students used the alternate conception of a ball having a force in the direction of its motion, indicating the object

Table III

Summary of Grade Nine Edmonton Students Answers to Question #1

Student Response	Students Not Planning to Take Physics	Students Planning to Take Physics	General Grade Science Student
Tangential	22.0% (N = 29)	18.6% (N = 34)	20.0% (N = 63)
Continues in a curve	43.9% (N = 58)	53.6% (N = 98)	49.5% (N = 156)
Straight out, angled between radial and the tangential	15.9% (N = 21)	13.7% (N = 25)	14.6% (N = 46)
Radially straight	3.8% (N = 5)	3.8% (N = 7)	3.8% (N = 12)
Other Responses	14.4% (N = 19)	10.4% (N = 19)	12.1% (N = 38)
Total Responses	(N = 132)	(N = 183)	(N = 315)

Figure 5



Tangential from Break

Straight from drawn Arrow

would travel straight forward because that was the direction of its force at break. For example, in supporting their tangential answer, two different students wrote:

> Before the line was cut, the ball is trying to go straight. But the line restricts it from doing so. Now the line is cut, the ball is free to go straight.

and

> The ball is carrying force and the string provides resistance. The ball wants to go straight so when the string breaks the ball will travel in a straight line.

Another student who drew a straight line from the direction of the arrow on the sketch wrote:

> The ball will go this way because at the time it breaks, it is heading in this specific direction.

There were a variety of curved path responses given for this answer, with 53.6% of physics bound, and 43.9% of non-physics bound students choosing this type of response (See Figure 6). Some paths

curved a little to become straight and some curved around until the ball was supposed to impact with the ground. In most of the cases, the ball curved out and away but there were responses that predicted a curve along the original path and even the odd one that expected a curve towards the center of the path. Almost every curved path started where the string broke and was drawn from the tangential, but there were also a few drawn radially outwards to then follow a curved path.

A number of student responses showed a curved path at an angle between the tangential and radial. Student responses to this indicated that the path was a result of the centrifugal force and the object's circular motion. For example:

> The force of going around in a circle will continue a bit. However, the force of being released from under the pressure of the string will cause it to fling itself away from its original path.

Other students drawing similar curves wrote:

> That's the way it's moving cause of the force pulling it out and in the direction its moving

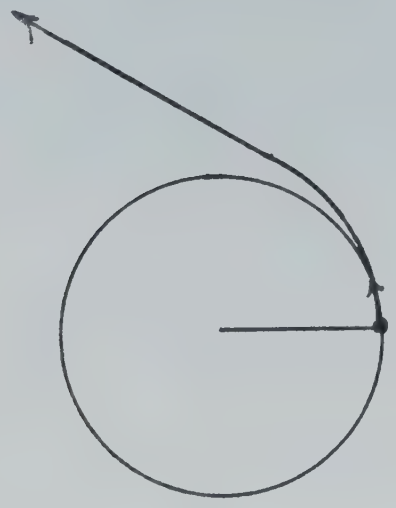
and

> The ball is rotating on the same path as it is spinning. When the string breaks, centrifugal force carries the ball away from the original path, but the ball still has a slight tendency to travel the old path.

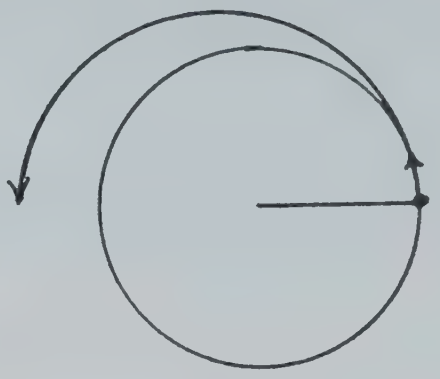
Students drawing curvilinear paths seemed to have a concept of circular impetus keeping the object moving in a curved path (after breaking free) until it wore out at which point it would travel in a straight line. Some examples illustrating this are:

> I believe it will continue to follow its previous course for a short period of time and then go off in a different direction. This will happen due to the force it has gained while rotating.

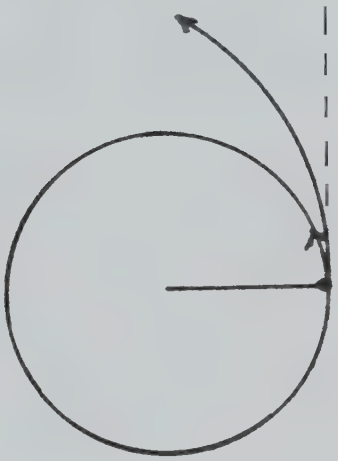
Figure 6



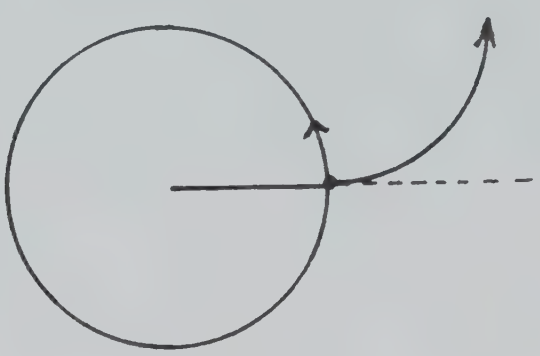
Curvilinear from Break



Continuous Curve from Break



Curve from Tangential



Curve from Radial

and

> The ball has a little momentum in it so it goes a short distance on its path. Then because of the momentum "wearing off" it goes in the direction that is shown. (Student drew a curvilinear path)

It was observed that in a number of instances reference was made to a spinning ball. This spinning notion was used to justify a number of

different curved paths and it was common to find associations between the orbital speed and the spin. For example:

> The ball keeps spinning because it cannot immediately stop the motion that it has been moving for so long. After all its energy or spin is out, it will fly away in one of the turns.

and

> The ball would still have momentum from spinning at a high speed. Therefore the ball would still be carried a little ways.

In a couple of instances, students directly stated that the object's spin would result in a curved path. One student referred to the motion of a released spinning top and the other stated from his own experience what the path should be, as follows:

> The ball would have a spin on it. Its like rocks in a sling. The ball is let go so it will not go straight.

Some of the students believed that the object would continue to curve until it impacted with the ground. Gravity, in this concept, was sometimes identified as the agent pushing or pulling the object down.

The "curving path drawn from the tangential" response seems to stem from consideration of only the object's forward motion and its circular impetus. An example of a student statement written in support of such a drawing is:

> The way the ball is going before the string breaks would affect its course causing it to curve. It would not go sideways because the force is behind it.

One misinterpretation of junior high instruction became evident in the case of two different students drawing a curved path and then invoking Newton's inertial law as support:

> An object in motion will want to stay in motion so the metal ball would curl in the direction it was swung before falling to the ground

and from the second student simply:

> An object in motion remains in motion until acted upon by another force

In other cases, students described the ball as being trained (conditioned) to move in a circular path, either having a pre-established pattern or making a circular path of air currents in which the ball will continue to follow. For example:

> The ball will almost be trained to the way it is going and continue in that direction until it leaves the orbit.

and

> The ball is flowing in one direction, moving the air currents which are going the way the ball is moving. So when the string breaks, the ball is caught up in the air current and is being carried the direction it was going in the first place.

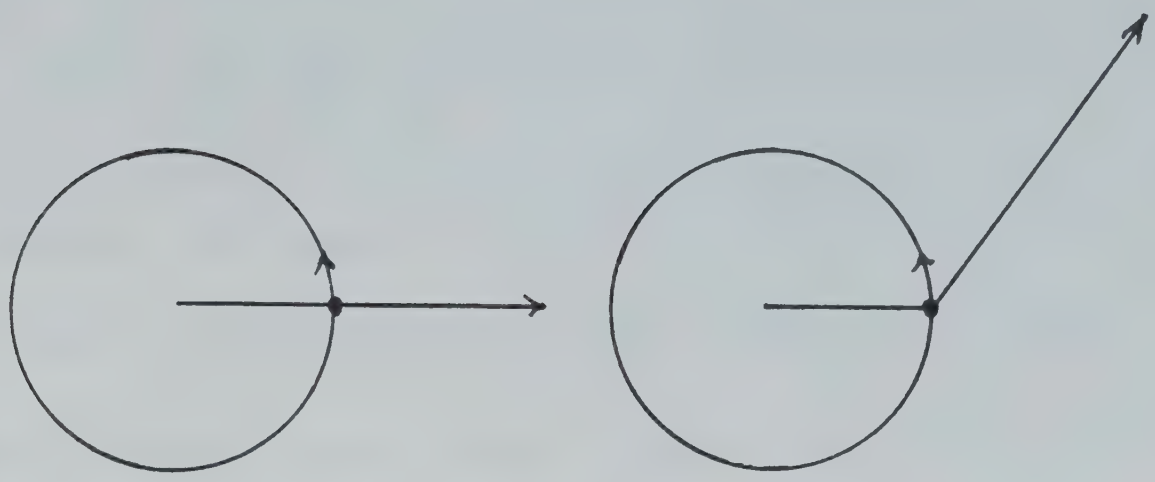
The straight path that angled somewhere between radially outward and tangential was chosen by 14.6% of the grade nine students with very little difference between the two groups (see Figure 7). Dominant student support for this type of path seemed to be a balancing of the forces moving the object: the force with which it was moving forward and the centrifugal force tending to move the object outwards. Some of the student responses clearly stating this are:

> There is force pushing out on the ball. There is also force pushing it forward. It takes the average of the two and goes out and forward.

with another student stating:

> The forward force combined with the centrifugal force will make the ball go in that direction.

Figure 7



Radial from Break

Angled between Radial and Tangential

The radial path was chosen on average by 3.8% of both groups of grade nine students. (see Figure 7) It appears that most students considered the radial path outwards a result of centrifugal force or a tug of war phenomenon, with the string pulling in and the ball naturally pulling out. Some of the student statements supporting this are:

> The centrifugal force will pull the ball straight out from where the string broke.

and

> All things travel in a straight line unless another force is acting on the object. The string is the other force which makes the ball go around so when the string breaks the ball flies outwards in a straight direction.

A large number of students (12.1% for general student) gave no response or responses which were difficult to classify. More of these came from the students not intending to take physics (14.4% verses only 10.4% of the students intending to take physics).

A number of students indicated that the ball would travel until it had slowed down. At this point the ball was perceived to drop. For example:

> The ball will continue to rotate until the speed stops. Then the ball will drop.

A few more students indicated that the ball would drop as soon as the string broke. For example:

> The ball would just drop straight to the ground because there is nothing holding it up.

Comparisons between Edmonton Student Responses and Other Studies

In the comparison of grade nine students with the John Hopkins University students one would expect to see some substantial differences due to the physics and science instruction already taken by the university students. Not much change was expected from maturation as the students' alternate conceptions often just become more sophisticated over time (Stephans, Beiswenger and Dyche, 1986; Clough, Driver and Wood Robinson, 1987).

Table IV indicates that half the university students correctly predicted the path of the released object compared to roughly 20% of the grade nine students. This is probably due to education, but the number of university students maintaining an impetus concept when confronted by a different situation (recall the curved pipe where the ball goes through 615 degrees of curvature (McCloskey, Caramazza and Green, 1980)) is interesting. This appears to indicate a lack of transference of the correct concept to other situations (compartmentalized knowledge, White, 1987), which makes the success of instruction questionable.

Table IV

Comparison of Grade Nine Edmonton Students Answers to Question #1 to Those of John Hopkins University Students

Student Response	John Hopkins University Students	Edmonton Students Planning to Take Physics	Edmonton Grade Nine Science Students
Tangential	50% (N = 25)	18.6% (N = 34)	20.0% (N = 63)
Continues in a curve	28% (N = 14)	53.6% (N = 98)	49.5% (N = 156)
Straight out, angled between radial and the tangential	6% (N = 3)	13.7% (N = 25)	14.6% (N = 46)
Radially straight	6% (N = 3)	3.8% (N = 7)	3.8% (N = 12)
Other Responses	10% (N = 5)	10.4% (N = 19)	12.1% (N = 38)
Total Responses	(N = 50)	(N = 183)	(N = 315)

There is a considerable difference in the two studies in students choosing a curved path (Table IV). To a lesser extent, the numbers of students choosing a response that the ball will travel in a straight line somewhere between the tangential and radial is over twice as prevalent amoungst the grade nine students as the university students.

Student statements supporting their answers appeared to involve a combination of common alternate conceptions including: motion implies a force, impetus and centrifugal forces. Students almost randomly used terms such as energy, force, motion and momentum in their explanations of their predicted paths. All of this has been found by previous research (Osborne, 1980; McCloskey, Caramazza and Green, 1980; Viennot, 1979; Gunstone, 1984 and Gardner, 1984). Also evident to some extent but not mentioned in these studies was the student concept of a tug of war phenomenon (rather than centripetal and centrifugal forces), where the string breaks, snapping inwards with the ball falling outwards. It appears, also, that little has been written about the student concept of the object's spin being a source of curved motion, perhaps having its origin in the curved motion of a spinning top on a flat surface or a curved baseball. The apparent lack of data on this aspect of curved motion should be addressed in future research.

Summary of Alternate Conceptions Found in Edmonton Student Study

In summary, a number of alternate conceptions were found to be used by the Edmonton grade nine students in addition to the correct concept.

The currently accepted concept is that an object will move in a straight line at a constant velocity if no external unbalanced forces

act on it. This concept was clearly used by a number of students where the string was identified as pulling the ball towards the center of the circle. Once the string broke, students thought that the ball would continue travelling in a straight line in the same direction.

The simplest alternate conception found in students was the belief that objects moving in a circular path tend (in the absence of an external force) to keep moving in a circular path. This extension of Aristotelian natural motion was found to be used by a number of students. Objects were described by students as wanting to keep moving in the same path or being trained to move in the same path. These student statements made no reference to an external force.

The most common student alternate conception was that a circular force or impetus could be given to an object. This impetus was considered to be of varying endurance and as such could affect the object's motion a small amount or could last until the object impacted with the ground. In one instance, a student made it evident that the object's circular motion changed the air currents in the path, and that these air currents would act on the object to continue moving it in a circle after the string broke.

One student alternate conception that has not yet been identified in the literature concerned the object's spin. Students felt that objects moving in a circular path were given a spin. This spin would then affect the object's motion causing it to move in a curved path. In a number of these cases, students made a direct association between the rotational speed of the object and its spin; the faster the rotation, the greater the spin and resulting curve.

Another popular student alternate conception was a tug of war situation resulting from the string pulling inwards and the ball pulling outwards. This conception sometimes resulted in students perceiving the ball to move straight outwards (students also coupled this conception with others to come to a number of different conclusions). In a few instances the students believed that the ball would tumble inwards as a result of the release of the string.

The last alternate conception identified in student usage was that the ball should drop straight down. These students believed that unsupported objects fall straight down. This conception is used to explain a great number of situations, including the dropping of an object from an aircraft, holding something outside a moving car or train window or even releasing something from outside a spaceship in an orbit. All of these objects are believed to fall straight down and all involve a failure of the student to consider the conservation the object's motion.

Student responses involved the use of one or several alternate conceptions in their answers. For example the perceived force in the direction of the object's motion and the tug of war conception could be combined to generate a path angled somewhere between the tangential and radial or on the other side from the radial. Likewise, the "circular force" could be combined with the "force straight forwards" or the tug of war conception to generate curving paths from the tangential, radial or others.

Student experience must also be recognized for its contribution in student concept formation. It can be inferred that a lack of precise

observational skills (of the exact direction of the object's motion at release) could lead to a student prediction that the object would fly forward but at an unpredictable slight angle on either side of the tangential. McCloskey (1983) suggested that the resulting motion in an observers head from throwing a heavier object (center of mass between the ball and observer rotating around each other), could lead to an observation of a curvilinear path.

Teachers Predictions of Edmonton Student Responses

Teachers responded to question #1 of the survey with a variety of different answers (see Table V) of which the most common was a tangential path (chosen by 17 teachers). Three teachers indicated that a nontangential path was the correct answer and gave no indication of any awareness of the tangential path. Of these three, one teacher drew a straight line from the direction of the arrow which was accepted as a correct answer from the students and was interpreted as a misinterpretation of the diagram. The remaining two teachers gave different common alternate conceptions as correct answers, the first believing that the ball would curve and then straighten, and the second believing the ball would travel in a straight line somewhere between the tangential and radial outwards.

Radially Outwards

The most common student alternate response expected by 13 teachers was a path drawn radially outwards. As shown in Table VI, the teachers

Table V

Summary of Teacher's Predictions of Student Responses to Question #1

Predicted Student Responses	Teachers Choosing Each Response	Mean of Teachers Predictions	Standard Deviation	Minimum and Maximum Predictions
Tangential	19/20	37.5%	21.4%	0 - 80%
Curved	10/20	38.9%	28.2%	5 - 75%
Radial Outwards	13/20	44.6%	24.9%	10 - 80%
Straight between Tangential and Radial	8/20	23.6%	16.3%	5 - 50%
Other Responses				
Drops	2/20	20%	0.0%	20%
Radial Inwards	2/20	10%	7.1%	5 - 15%
No Idea	2/20	32.5%	24.8%	15 - 50%
Curves from Tangential to Radial Outwards	1/20	15%	0.0%	15%
Curves from Radial Outwards to Tangential	1/20	50%	0.0%	50%

overestimated the prevalence of this response from their students by almost 12 times.

Nine of these 13 teachers mentioned that students would be aware of either a force being required to hold the ball in a circular path or the observable tension in the string holding the ball in. Almost all of these teachers felt that experience from the real world would lead them to choose such a path. One teacher explained it as follows:

> If they were holding that string they would have a tendency to feel a pull in their hand; I think they would have the impression that it's pulling straight out along the radius.

Another teacher explained

> Based upon their own observations, in that if you are on a ride and you are moving in a circle then you have this feeling that you are being pushed out. For example the ride at the exhibition where you used to spin around, stick against the wall and the floor would drop out.

One of these teachers explained this as a misinterpretation of Newtons 3rd law:

> They're going to feel the force on the, you know the, centripetal force on the wire or the string and when that string snaps since the force is directed straight inwards towards the center of rotation, you know, uh, got to go the other way, I think most of them are, probably get sort of the idea of the action-reaction thing, Newton's third law kind of business there.

Two teachers explained that students might choose the radially outwards path due to the centrifugal force acting on it. One of the teachers mentions the response to be a misunderstanding of centrifugal force, that is:

> If they have taken or heard a little about centrifugal, perhaps they would have thought well there is a force, centrifugal force that's pushing it out.

The other of these two teachers mentions both experience and centrifugal forces as being possible sources for this student alternate conception. For example:

> I would guess that maybe there's a conflict between something in them that tells them an object is pulled away from the center of a circle, the old centrifugal force, that they always, somebody always mentions, centrifugal force, and that pulls things away from the center... .

Of the two remaining teachers predicting such a student response, one felt it "was a logical response at the time", with the other just believing the students were guessing.

Curved Paths

Curved paths were predicted by half of the teachers, who believed that their students would draw a continuous curve or a curvilinear path. Two other teachers predicted a curved path, one curving from the tangential to the radial and the second curving from the radial to the tangential.

Of these ten teachers only seven stated some type of reason as to why the students would choose a curved path. One teacher who had asked his students (prior to my contact with him) to predict the path of an object that was released after being swung over their heads stated:

> The ball is already going in a curved path, it's still got to keep going in a curved path. It's just going to fly off because you have now let go of the string. ... Initially it was in a curved path and it still got to have that quality about it. It's still got to have that curve.

Another teacher explained his reasoning as follows:

> Once the string breaks here the idea is that it would fall away from the direction that it was going. Like in the opposite direction so to speak. When this breaks it would go further away than from before because now that attachment

> is not there. The string was keeping it equidistant and once it broke then it would tend to move further away.

Three teachers expected that the students would think the ball would curve for a bit before moving off on some path. Only one of these teachers mentioned students having some inherent idea of inertia, more specifically:

> Others might assume that it's going to maintain it's path for a short while and then deviate ... Possibly, some inherent idea of ... about inertia, the idea that an object that is moving in a particular way continues to move that way. That's possible.

The second of these two teachers mentioned only:

> Say it is in a circle because it was going in a circle and things keep wanting to do their own thing. So it will want to keep doing its own thing and keep going in a circle at least for a little while.

The third teacher felt the students just did not think about it and would therefore believe that the ball would continue in the same direction.

One teacher felt the students might think the ball would spiral inwards till impact. In a few instances students did respond in such a manner. The reasoning given by the teacher was that the students might compare this to the decaying orbit of a satellite, for example:

> Some students, maybe a minority might think it spiral in for no good reason. Some of them may have the idea that this represents a planetary orbit or satellite orbit and that it's in a decay process. Some might have that association.

One of the teachers interviewed felt that the ball itself would travel in a curved path. This teacher was uncertain as to whether the ball would continue to curve or would just curve a bit before straightening out.

Linear Path at Varying Angles from Tangential

The last common path, predicted by 8 teachers, was a straight line drawn at some angle between the tangential and the radial. Five out of these 8 teachers stated that experience would be the main factor (one of these believed it could also come from instruction). All of these teachers indicated that an observer would see the ball fly off in a straight line and would be unaware of the angle it had left at. As one teacher stated:

> ... even if they think of a yoyo and they twirl it around and they know that if they let the yoyo go that it shoots straight out, but they don't know at which point they let it go so it does look like it shoots out at an angle. It does appear that it shoots out at an angle, not realizing where they let it go from.

One of these five teachers thought the ball would fly off at some angle. He was aware of the tangential answer but appeared to reject it from experience and felt that if the students had no experience they would choose the tangential path. He describes this as follows:

> From everyday experience, they won't, there's no rationale at that level for them to ah, if they'd played this game from before and that's all they have to go on, myself included, I haven't taught angular momentum and it's so long, I have no more to go on than they do at this moment. Just from everyday experience, that's all it would probably. I would think if they haven't played this game at all they would choose this one (tangential). It will fly off in these directions, right? I think.

The one teacher that also thought instruction had something to do with the student response explained his reasoning as follows:

> I think that they have this innate desire to see things fly away from the center but there may be something either from their instruction or from their experience, that tells them it goes in the direction that you are, that it is moving when it's released. And something prevents them from drawing it in this direction so they may think that it's a little

> of both and put down the in between. I'm sure I've seen this.

One teacher felt that students might choose an angled path from an awareness of the tangential and radial outwards path. This teacher felt that the students would simply choose the middle of these two.

The two remaining teachers of the eight gave explanations that seem to fit in the radially outward path explanations. Both of them specifically mentioned the path would be at some angle between the tangential and radial, and that the string was no longer pulling inwards to the center. Neither of these two made any mention of students choosing a radially outwards path and they did not state any reason for the ball to continue forward. As one teacher described his reasoning:

> If it had been swung really hard again since there's no inward pull, it would just take off in another direction. It would go away from the center cause the center is not pulling it in anymore.

Other Paths

There were a few other predictions made by physics teachers that were not shared in general by the others. Two teachers felt some students believed the ball would drop as soon as it broke free and two other teachers felt a few students would believe the ball would recoil inwards. Two teachers, including the one who gave an alternate answer that the ball would drop, felt on average that some students would have no idea what the answer was and simply not answer the question.

Students drew every path predicted by the teachers and more, except the path that curved from the radial outward to parallel the tangential. However only four paths chosen by teachers were found to be common with

students; tangential, curved, radially outwards and straight out angled between the tangential and radial.

Comparison of Edmonton Physics Teachers Predictions to the Edmonton Student Study and other Research.

As one can see in Table VI, the average of the teacher predictions of students picking different responses show that the teachers (who indicated awareness of these different answers) have little idea of their prevalence with their students. In the instance of the correct answer, the predictions of the number of students attaining it are closer to the results from the John Hopkins university students. The worst of all teacher predictions however, was the number of students choosing the radially outwards path. In this instance, student response was overestimated by almost 1200%.

Alternate Conceptions Summary

There were five alternate conceptions found in the Edmonton grade nine student explanations of their answers to question #1 of which all were identified by the Edmonton physics teachers. One alternate conception identified by a teacher that the ball should curve into the center like the decaying orbit of a satellite was not found in either the literature or in the student survey. However the path resulting from such a conception was drawn by several students (This response could also result from two different student-held alternate conceptions; where the ball falls inwards from the tug of war conception and where the ball was given a circular force).

Table VI

Comparison of Physics Teachers Expectations of Question #1 to Grade Nine Edmonton Students and John Hopkins University Students

Student Response	John Hopkins University Students	Edmonton Students Planning to Take Physics	Edmonton Physics Teachers Prediction
Tangential	50%	18.6%	37.5%
Continues in a curve	28%	53.6%	38.9%
Straight out, angled between radial and the tangential	6%	13.7%	23.6%
Radially straight	6%	3.8%	44.6%
Other responses	10%	10.4%	
Total responses	(N = 50)	(N = 183)	

The most common alternate conception identified by nine teachers (total of 9) was the tug of war conception. Such a conception (commonly found in research but referred to as the centrifugal force pulling outwards) was most often believed to result from experience, where the ball could be felt to pull outwards from the center. Two of the teachers mentioned that students might use the reverse logic or hold some idea of a mystical attraction towards the center to believe that the ball would fall inwards.

The most common student alternate conception that a circular force or impetus could be given to an object was identified by three teachers (one of these three believed it to be the correct concept). These teachers all felt that some students would hold an idea where the object would continue in a curved path for some distance before going straight. Although only one teacher mentioned circular impetus, the other two teachers implied such a concept. No teacher indicated that circular impetus would be used by students to draw a path that curved until impacting the ground or mentioned circular force. That objects could shape the environment (e.g. creating a vortice of circular air currents) to sustain such a motion was also unmentioned.

The concept of natural motion was described by one teacher and implied by a second. The first of these teachers had asked similar questions in his classroom and believed that 3/4 of the students hold it, whereas the second thought students would respond this way without thinking.

The two remaining alternate conceptions were identified by a single teacher each. That unsupported objects drop straight down was

identified by a teacher who recalled holding the same conception from his childhood. The other conception, that objects moving in a circle are given a spin which then causes them to continue to curve, was believed to be true by one teacher.

In no instances did the Edmonton teachers indicate that students could use several alternate conceptions in unison to derive an answer.

Student experience was recognized by four teachers as a source for the ball travelling forwards at varying angles from the tangential. Three teachers identified an inability to accurately quantify the angle of ball movement to the release point as the key factor in conceptualizing experience. The remaining teacher of these four cited personal experience as evidence that a straight angled path was correct.

Question #2

Edmonton Grade Nine Student Responses

Question #2 was drawn originally from Osborne's 1982 study, looking at the student conceptual relationship between force and motion. This question showed a stick man with a bent arm held out to one side and a ball a short distance above the hand. The students were asked to identify the total force acting on the ball at three different positions: on the way up, at the highest point and on the way back down.

The accepted answer for question #2 was that the net force acting on the tennis ball would be directed downwards throughout the flight of the ball. As indicated in Table VII few grade nine science students chose this as the correct answer; only 6.0% of the students intending to take physics with slightly more (7.6%) of the students not intending to take physics.

Where the correct answer was chosen, student explanations tended to be short and concise. Common examples of such are:

> Gravity is constantly pulling the ball down.

and

> Gravity is always pulling on the ball regardless of where it is or how fast it is moving.

The most common response (see Table VII) from the grade nine students was that the force was in the same direction as the object's motion. More of the physics bound students (61.2%) considered this to be the correct answer than the non-physics bound students (49.2%).

Table VII

Summary of Grade Nine Edmonton Students Answers to Question #2

Student Response	Students Not Planning to take Physics	Students Planning to take Physics	General Grade Nine Science Students
On Way Up ... Force Up At The Top ... No Force On Way Down ... Force Down	49.2% (N = 65)	61.2% (N = 112)	56.2% (N = 177)
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Up	9.1% (N = 12)	10.4% (N = 19)	9.8% (N = 31)
On Way Up ... Force Up At The Top ... Force Down On Way Down ... Force Down	9.8% (N = 13)	8.2% (N = 15)	8.9% (N = 28)
On Way Up ... Force Down At The Top ... Force Down On Way Down ... Force Down	7.6% (N = 10)	6.0% (N = 11)	6.7% (N = 21)
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Down	5.3% (N = 7)	3.3% (N = 6)	4.1% (N = 13)
Other Responses	18.9% (N = 25)	10.9% (N = 20)	14.3% (N = 45)
Total Responses	(N = 132)	(N = 183)	(N = 315)

The most common defense given by students for this response was that the force was acting in the same direction as the object's motion. This was clearly evident, and was often found in student responses such as:

> The force is always in the same direction the object is moving.

and

> In each case the force is pushing the ball in the direction it is moving. If it is not moving then there is no force acting on it.

In more elaborate student responses, clear detailed explanations outlined a concept of a force given to the object during the action of throwing it upwards. At the top of the flight the force upwards was thought to be balanced by the gravitational force pulling the object down. As the object began to fall down gravity was often described as the dominant force acting on the object. For example, as some students wrote:

> When the ball is thrown upward the force of the arm drives it upward. As the ball reaches the top of its flight the gravity and upward motion become equal, therefore there is no dominating force. As the ball comes down the upward motion has disappeared, therefore the force of gravity dominates and pulls the ball downward.

and

> In order for the ball to go up the upward force has to be greater than the force of gravity. When the ball is at the top of its flight the upward force and the gravitational force are equal. As the ball descends the gravitational force becomes greater than the force of the throw.

Some students, in explaining their response, indicated gravity "switching on" at the top of the flight, after the upward force had "dissipated", to pull the ball back down. As one student wrote:

> The force emitted by the person allows the ball to be thrown upwards. As the ball is at the top, it rests, suspended with no force, as nothing is being done. The force of gravity then pulls the ball back down into the person's hand.

The next most common response held by these grade nine students was that the force was in the opposite direction to the motion of the object. This response was chosen by 9.8% of the grade nine students on average, with 10.4% of the physics bound students choosing this response compared to 9.1% of the non physics bound students.

There seemed to be two distinct lines of reasoning used by students believing that the force was in the opposite direction to the object's motion. The most common of these appears to consider the net force to be the action of air resistance. For example, as several students explained:

> When the ball is going up there is wind resistance and the same for when it is going down. But when it is at the top of it's flight it isn't going up or down for a split second, so there is no force on the ball.

and

> In #1 it is going up so the resistance (force) is pushing down. In #2 it is not moving so there is no force. In #3 the ball is going down so the resistance (force) is on the bottom of the ball.

In some other explanations, students used a combined notion of gravity and air pressure to explain the forces acting on the ball, for example:

> The force on the ball on the way up is gravity, on the way down it's air pressure and at top flight is no force.

and

> Going up gravity is in effect, so the force is downwards. The top of it's flight it has no force. Going down the air resistance keeps pushing up on the ball.

Another common response from the grade nine students was that the force should be up as the ball rises but when the ball stops at the top the net force is then directed downwards and remains downwards as it falls back down. Of the students choosing to take physics in high school 8.2% chose this response, as compared to 9.8% of the students not intending to take physics.

The most common explanation given by students choosing this type of response involved upward movement of the object because some upward force is given to it. These students thought that after the upward force wears out, gravity then pulls it back to the earth. For example some students wrote:

> When you throw up the ball, the force of you pushing outweighs the force of gravity. However, when it gets to the top of it's flight the force of gravity stops it and pulls it down again.

and

> Gravity pushes the ball down when the ball has no more upward force.

This reasoning is very similar to those students who thought there was a force upwards when on the way up, no force when at the top and a force downwards on the way down (see page 74).

The last response that was chosen by a significant percentage of students was that the force would be down on the way upwards, with no force at the top when the object stopped, and then downwards again as the object began to fall back down. This response was chosen by 5.3% of

the students not intending to take physics and only 3.3% of the students intending to take physics.

Students who chose this response indicated that gravity acts on the ball only when it is in motion, either up or down. At the top, however, it is stationary and the students appear to make a link between force and motion. For example, as some students explained:

> At the top of the flight the ball is just hovering so there is no force on it. On the way up gravity is pushing against it and on the way down gravity is with the ball.

and

> When the ball is going up the gravitational forces are still on it otherwise it would stay still or keep going up. It is in the air with no force because it is not moving. The way down it is being pulled by gravity.

Comparisons between Edmonton Student Responses and Other Studies

Comparing the student results of this study to the Osborne study (1982), one finds little difference between them (see Table VIII). The grade nine students of Edmonton are mostly 14 and 15 year old students and one finds the results from both the students planning to take physics and the general grade nine students closely agree with Osborne's numbers for his students of the same ages.

One apparent difference was in the percentage of students attaining the correct answer. Osborne's 14 year old students averaged at 10.8% and his 15 year old students 5.7%. The general Edmonton grade nine student population averaged 6.7% with the students who were planning to take physics who averaging 6.0%.

Table VIII

Comparison of Grade Nine Edmonton Students Answers to Question #2 to Those of Osborne's 1982 Study

Student Response	Edmonton Students Planning to take Physics	Edmonton General Grade Nine Students	Osborne (1982) Students 14 years of Age	Osborne (1982) Students 15 years of Age
On Way Up ... Force Up At The Top ... No Force On Way Down ... Force Down	61.2% (N = 112)	56.2% (N = 177)	52.8% (N = 103)	66.1% (N = 115)
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Up	10.4% (N = 19)	9.8% (N = 31)	10.3% (N = 20)	9.8% (N = 17)
On Way Up ... Force Up At The Top ... Force Down On Way Down ... Force Down	8.2% (N = 15)	8.9% (N = 28)	10.8% (N = 21)	9.2% (N = 16)
On Way Up ... Force Down At The Top ... Force Down On Way Down ... Force Down	6.0% (N = 11)	6.7% (N = 21)	10.8% (N = 21)	5.7% (N = 10)
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Down	3.3% (N = 6)	4.1% (N = 13)	5.1% (N = 10)	5.2% (N = 9)
Other Responses	10.9% (N = 20)	14.3% (N = 45)	10.3% (N = 20)	4.0% (N = 7)
Total Responses	(N = 183)	(N = 315)	(N = 195)	(N = 174)

In summary there appears to be little, if any, difference between the Edmonton grade nine students and the New Zealand 14 and 15 year old students in answering this question.

Summary of Alternate Conceptions Found in Edmonton Student Study

The Edmonton grade nine students explained their answers to question #2 using a number of different alternate conceptions including the correct concept.

The desired conception from the grade nine students was that in the absence of air resistance the force of gravity is the only force acting on the ball and thus the net force acting throughout the entire event. This concept was clearly used by a number of students in their response to this question. There was little reference made by the students to air resistance, even though they were not instructed to ignore its effect on the ball.

The most common of all the student-held alternate conceptions was that the force acting on a body is in the same direction as the motion. About half the Edmonton students used this concept where the direction of an object's motion was taken as evidence of a force acting upon it in the same direction. In a number of instances students believed gravity to be the net force acting throughout the entire event (a result of instruction) except at the top. Students appear to compartmentalize the concept; accept it in some other instances while rejecting it in others.

The next most common alternate conception involved the concept of a force or impetus given to an object when it is thrown. This conception was often found to be used simultaneously with the concept of a force

in the same direction as the object's motion. This force was perceived to weaken, dissipate or just disappear as the object moved upwards.

It appears that a student's concept of the influence of gravity acting on the ball was modified by the student holding either one or both of the above two common alternate conceptions to create at least three distinct but similar conceptions of gravitational influence. The most common of these involved the use of both alternate conceptions mentioned above and gravity acting throughout. The object was given an impetus upward (force) and was perceived to move upwards only because the impetus given to the ball was greater than the force of gravity. As the impetus weakened (or dissipated), the ball slowed until it stopped, at which point the force of gravity balanced the impetus upward (no net force here). Gravity then acted to begin pulling the ball downwards throughout the rest of the motion. A second although similar conception involved a perception of the ball given an impetus upwards. This ball rose until the impetus had dissipated or disappeared. The ball was perceived to stop with no forces acting upon it. Students then believed that gravity acted to pull the ball back down. The last of these conceptions considered the ball to be given an impetus upwards. The ball was perceived to rise upwards until the impetus dissipated. The ball was not considered to stop at the top, rather it was considered to immediately begin to fall downwards again due to the influence of gravity.

A number of students were also found to use a conception of the force acting in the opposite direction to the object's motion. In a large number of these instances students believed air resistance to be

the net force acting on the ball. However, there were less common alternate conceptions found to be used by the students.

There were also other, less common alternate conceptions found to be used by the Edmonton students. They are as follows:

1. Gravity only acts to slow the object while it is moving upwards.
2. Air pressure forces object down to the earth's surface.
3. No force acts on an object thrown upwards while it is moving upwards.

In this study there were two dominant student alternate conceptions; the force acting on an object is in the same direction as its motion, and a force is "given" to an object when it is thrown. There were various conceptions of the influence of gravity on the ball, but all appeared to be modified by the two major alternate conceptions.

Teachers Predictions of Edmonton Student Responses

The Edmonton physics teachers predictions of the student responses to question #2 indicate a strong awareness of only one alternate conception, a partial awareness of another and a prevalent belief in a student alternate conception that was not found to exist.

Fifteen out of the 20 teachers felt that some number of students (predicted average of 11.5%) would state that the net force acting on the ball throughout the event was downwards and was due to the gravitational attraction of the earth. Six out of the 20 teachers although aware of the fact that gravity was acting in all parts of the motion, believed the net force was always acting in the direction of an object's motion! One of these six teachers commented on the difficulty

Table IX

Summary of Teacher's Predictions of Student Responses to Question #2

Predicted Student Responses	Teachers Predicting Each Response	Mean of Teachers Predictions	Standard Deviation	Maximum and Minimum Predictions
On Way Up .. Force Up At The Top .. No Force On Way Down .. Force Down	19/20	32.5%	33.0%	0 - 100%
On Way Up .. Force Down At The Top .. No Force On Way Down .. Force Up	6/20	0.8%	1.7%	0 - 4.8%
On Way Up .. Force Up At The Top .. Force Down On Way Down .. Force Down	16/20	16.7%	15.6%	0 - 64%
On Way Up .. Force Down At The Top .. Force Down On Way Down .. Force Down	15/20	11.5%	14.5%	0 - 40.9%
On Way Up .. Force Down At The Top .. No Force On Way Down .. Force Down	14/20	6.8%	7.2%	0 - 22.5%
Other Responses	17/20	31.7%		

Table X

Comparison of Physics Teachers Expectations of Question #2 to Grade Nine Edmonton Students and Osborne's 1982 Study

Student Response	Edmonton Students Planning to Take Physics	Edmonton General Grade Nine Student	Osborne (1982) Student 15 years of Age	Edmonton Physics Teachers Predictions
On Way Up ... Force Up At The Top ... No Force On Way Down ... Force Down	61.2%	56.2%	66.1%	32.5%
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Up	10.4%	9.8%	9.8%	0.8%
On Way Up ... Force Up At The Top ... Force Down On Way Down ... Force Down	8.2%	8.9%	9.2%	16.7%
On Way Up ... Force Down At The Top ... Force Down On Way Down ... Force Down	6.0%	6.7%	5.7%	11.5%
On Way Up ... Force Down At The Top ... No Force On Way Down ... Force Down	3.3%	4.1%	5.2%	6.8%
Other Responses	10.9%	14.3%	4.0%	31.7%
Total Responses	(N = 183)	(N = 315)	(N = 174)	

of teaching students holding the incorrect answer (that gravity was acting down throughout the entire event).

Since the teachers were not asked to predict the popularity of different groupings of choices (there were 36 different), the popularity of groups had to be inferred (See Appendix 5 for method, results summarized in Tables IX and X). In most instances the teachers explained the students reasoning for choosing a single choice. Only in a few instances did teachers state that a group of students would choose a group of responses (For example, force acting in the direction of the object's motion was such a commonly identified response grouping). The explanation of expected student choices have been analyzed below to indicate teacher awareness of alternate concepts and not the predicted student grouping of choices.

Force is Always in the Direction of the Motion

Every teacher except one expected that students commonly associate force with a motion, with six teachers believing and teaching that the net force is always in the direction of an object's motion. The mean of the teachers predictions was 32.5%, with two teachers believing that all of their students would hold this conception. As some teachers stated:

> If the ball is on the way up, the force is also on the way up, because if we are looking at forces they (students) have some intuitive idea that forces result in motion, so if the thing is going up, then it must experience a force up.

and

> Things that move upwards are reacting to a force upwards. Things that move downwards are reacting to a force downwards. Things that are not moving, or at that top part, there is no force otherwise they would be moving. This is the idea that things that are moving require a force to keep

> moving in that direction. The old idea that if I want to move an object from A to B, I am going to have to apply a force. Sort of a negation of the inertial idea. You need a force for motion.

One of these twenty teachers felt that students conceptualize Newton's second law to be force equals mass times speed rather than mass times acceleration. For example:

> (There) is no distinction between v and g, between acceleration and velocity. That means that they don't understand this. The meaning of this, (2nd law) maybe its mv.

Force or Impetus Can be Given to Objects

The alternate conception that a force or impetus can be given to objects was identified by five different teachers and was the only other alternate conception to be identified by more than a couple of teachers. These five teachers all made reference only to this force acting on the way upwards. For example:

> They have a difficult time grasping that something moves in a given direction without a force acting on it. You throw something, after you let it go you feel that there is still a force acting that what makes it go.

There was only one teacher who recognized student confusion over what would happen to the upward force at the top. As this teacher stated:

> Since there was a force up to start with, that force didn't sort of vanish, so maybe it is still there and they do not know why it stops. So they think it should maybe keep going, or they are not sure what is going to happen.

Although another teacher did not describe in detail what he meant, his explanation suggests that he considers students to have a concept of balanced forces at the top of the trajectory. The second force is

identified as gravity but it is not clear whether he is aware that the first force is the force given to the object to go upwards:

> In the second situation at the very top of its flight, a higher percent of the kids will say that at that point, everything is balanced. Okay, there's nothing acting on it because it's stationary. They won't realize, I think even grade 12 students still don't totally understand that at that point there is still gravity acting on it, still accelerating and changing direction. I have this question on the physics 30 exam, and the only reason a student might get it is because of a guess. But I'll say that at the top of it's flight, which of the following is acting on the object, gravity, velocity, or which of the following is not zero, gravity, velocity, and things like that, and they'll know velocity is zero but they will not know that gravity (is acting and) will calculate that gravity is zero.

Conceptions of Gravitational Influence on Motion

One teacher felt that students would think in terms of two forces, where one force (or impetus) is given upwards to the object and the the other force is gravity acting downwards. Thus the student must think that for the object to move upwards, the force upwards must be greater than the force of gravity. In his words:

> Throw it straight up, the force on the ball would be up, if you are throwing it up. But if you are throwing it up then the force up has to be greater than the force down.

It is clear from this statement that this teacher expects his students to realize that gravity acts throughout the entire event, however the impetus was perceived to wear out before gravity could act to pull it back down again. At the top, the teacher believes that students think that there is no force acting on the object, because the remaining impetus just balances the force of gravity.

One teacher believed that some students would expect gravity to act only after the object begins to fall. For example:

> Soon as you let it go then there are no obvious forces acting on it, so there can't be any force. You are not touching it so there is no force. To them force only appears by contact and nothing else. (And on the way down) most of them by now will say, oh yes, it's gravity that brings it down, so all of a sudden they will remember, even though there is no contact, that gravity will work on the way down.

Two teachers believed that some students might perceive that no force acts on the object as it moves upwards. As one teacher described the conception:

> They have no concept of gravity acting on an object going upwards. They think that there are no forces acting on it, until you tell them, "Then why is it slowing down, why does it come to a stop?" and then all of a sudden, to that point they have no idea as to why that thing is stopping. 10% might say, well, something is pulling it back down, that's why it's slowing down, nobody will choose that there's a force acting on it downwards.

The concept of gravity acting on an object when it was moving upwards and downwards, but not at the top, was identified by only one teacher. This teacher hints that this causes some difficulty in instruction. For example:

> When its on its way up and on its way down, gravitation is acting down. They might have an idea of gravitation acting downwards, but at the top something has happened magically and the force suddenly shuts off. We have had kids who have suddenly decided that when the thing reaches the top you can ignore anything that happens from that point on, so all objects are floating at whatever height they happen to reach.

In this instance, the teacher although aware of the problem, is not aware of two of the possible sources; either the students are still using a modified concept of a force implies motion, or they consider the object to stop for a finite time at the top.

The Object Stops for a Finite Amount of Time at the Top

Two other teachers felt that some students would believe that the object actually stops for a finite time when at the highest point in the trajectory. This concept combined with the conception of a force acting in the direction of motion, would result in a student believing that no force acts on the object when at the top. For example:

> The ball is now stopped in motion actually, for that brief instantaneous second relative to the ground, it's motionless and I would suspect because of that they would choose the third diagram, no force acting on the ball. They would say if you could take a quick, take a camera with a very, very high shutter speed and take a photograph of it, you would see this ball stationary at the top of its flight and to them, they would think in effect its weightless at that point, no forces in action.

This explanation of weightlessness is one alternate conception predicted by a teacher that, although common in space situations, has not been applied to motion on the earth previously.

The other teacher believed that the object actually stopped at the top for a finite amount of time. For example:

> Not knowing the concept, you know if something has gone right to the top, right, it's stopped momentarily, for a fraction of a second. Then it begins to come down.

No Visible Contact, No Force

Half of the teachers felt that a number of students would hold a concept of "No Contact ... No Force." This conception has not been found to be used by Edmonton students. It is surprising that such a large number of teachers predicted a response that none of the students chose. The concept of a force acting at a distance has been historically difficult to understand (Isaac Newton), and it is expected

that a number of teachers would recognize this fact. However, no students were found to be using it.

Known Alternate Conceptions Not Identified By Edmonton Teachers

There were a number of common and less common alternate conceptions used by students that the Edmonton teachers indicated no awareness of. Two common alternate conceptions held by students and not identified by the teachers are: "the force acting on an object is in the opposite direction to its motion" and "gravity begins to act on an object thrown upwards only when it comes to a stop and continues to act as it falls" (or is responsible for the motion of the ball at the top and on the way down). Other alternate conceptions that were not identified by the teachers and were used to a lesser extent by students were: "gravity only acts on objects that are moving upwards", "air pressure forces objects down to the earth" and "an object thrown upwards does not stop, only reverses direction".

Comparison of Edmonton Physics Teachers Predictions to the Edmonton Student Study and Other Research

As Table X indicates, the inferred teacher predictions do not match up at all with the actual student findings. In all six recorded categories, the teachers' expectations were either about twice as high or half of the actual.

In the instance of the grouped response where the force was perceived to be in the opposite direction to the objects motion, the

teachers' inferred response (less than 1%) indicates a near total lack of awareness of the 10% student population answering this way.

Alternate Conceptions Summary

There were three dominant alternate conceptions found to be used by the Edmonton grade nine students;

1. The force acting on a body is always in the direction of an object's motion.
2. Force or impetus can be given to a body.
3. The force acting on a body is in the opposite direction to the motion of the body.

The student perception of what happens to the ball at the top of the trajectory could also be separated into three distinct groups, where:

P.1 The object comes to a finite stop at the top.

P.2 The object comes to an instantaneous stop at the top.

P.3 The object does not stop, merely changes direction.

It was found that students used at least five different conceptions of gravity that would agree with these alternate conceptions and one gravitational conception that retained a trace of the first alternate conception. These are:

G.1 Gravity only acts when the object is falling.

G.2 Gravity acts throughout the motion but is only strong enough to move the object in its direction when the impetus has weakened enough.

G.3 Gravity balances the impetus at the top.

G.4 Gravity is the dominant force at the top.

G.5 Gravity acts on the object to pull it down only after the upward impetus has worn out.

G.6 Gravity acts on the object moving upwards and downwards but not when it is stopped at the top.

Of the three alternate conceptions, 95% of the teachers indicated awareness of the first, that a force acts in the direction of an object's motion, with 30% of them believing it to be true. Twenty-five percent of the teachers indicated awareness of the conception that force or impetus could be given to an object. The remaining alternate conception that the force acting on a body is in the opposite direction to the objects motion, was not identified by any teacher. At best only 10% of the teachers indicated awareness of one or more of the three student perceptions about the motion at the top of the path and six student conceptions about the influence of gravity on the motion of the ball.

Half of all the teachers believed that students would have a conception of "No visible contact, no force". This was not found in the student study but has been historically recorded as a point of contention between British post Newtownian physicicsts and European physicicsts of the eighteenth century.

Question #3

Edmonton Grade Nine Student Responses

Question #3 involved having the students predict the position of an astronaut when his spacecraft had orbited to over the north pole, if he let go of the spacecraft (while in a polar orbit) over the equator. The desired answer from the grade nine students was that the astronaut would also be at the north pole, in nearly the same position as when contact was broken because the centripetal acceleration acting on both objects was the same and both had the same initial orbital radius and velocity at separation.

The position of the astronaut was correctly predicted by 37.7% of the students intending to take physics and only 17.4% of those not intending to take physics (Table XI).

It was found however that most of the students predicting the correct position of the astronaut did so due to a belief in some alternate conception. The most commonly held of these was that the astronaut in space was not experiencing any forces or gravity and, therefore, should continue to orbit beside the spacecraft because of Natural Motion. For example:

> He moves with the ship because there is no gravity and no force in space. So when something moves one way it stays going that way until it hits something solid.

and

> In space you move in the same direction you started moving in until the time you make another movement. Therefore if he is orbiting the earth and makes no movement to change this orbit, he will keep orbiting the earth.

Table XI

Summary of Grade Nine Edmonton Students Answers to Question #3

Student Response	Students Not Planning to Take Physics	Students Planning to Take Physics	General Grade Nine Science Student
Stays with Spacecraft	17.4% (N = 23)	37.7% (N = 69)	29.2% (N = 92)
Falls Behind in Orbit	9.8% (N = 13)	7.7% (N = 14)	8.6% (N = 27)
Remains at Equator	17.4% (N = 23)	18.6% (N = 34)	18.1% (N = 57)
Falls toward Earth	9.1% (N = 12)	4.9% (N = 9)	6.6% (N = 21)
Drifts Outwards from the Earth	13.6% (N = 18)	11.4% (N = 21)	12.4% (N = 39)
Other Responses	32.6% (N = 43)	19.7% (N = 36)	25.1% (N = 79)
Total Responses	(N = 132)	(N = 183)	(N = 315)

Other Responses include; No answer, Falling to the South Pole, Drifting Anywhere and Unpredictable, Orbiting the Equator, etc.

Another common alternate conception found to be present in the explanations accompanying correct student predictions was an indication of a force pulling the astronaut forward in orbit. For example:

> The ship acts as a magnet like when you are on the earth.

and

> The astronaut will be beside the spaceship moving north towards the north pole, because he will be caught up in the air currents with the spaceship and will float by the spaceship.

Astronaut Moving Behind the Spacecraft

Slightly fewer than 10% of the students felt that the astronaut would be found somewhere behind the spacecraft. Students indicating this response generally considered that there was some "force" moving the spacecraft that was stronger than the astronaut's "force". For instance, students thought that since the spacecraft weighs more, there is a greater gravitational force acting on it, or the spacecraft has an engine moving it forward and the astronaut does not. For example, some students wrote:

> The spaceship orbits the earth using no power from the ship. This is because of the gravitational force. The same type force acting on the spaceman but since the spaceman is lighter, the force is less causing the spaceship to move more rapidly.

and

> When he let go, some momentum he had from being towed by the ship caused him to drift in the same direction. The ship moves faster because it's being propelled, however the man doesn't move as fast as the ship because he isn't being propelled.

In several cases, students indicated that the spaceship was dragging or pulling the astronaut behind, almost as if they were

thinking of the vortices created by the passage of some object through the air causing small objects to be moved in the direction of the object's motion. Some examples of this are:

> Because the spaceship would pull the astronaut along.

and

> He will be floating somewhere between where he let go and where the ship is over the north pole because he will be pulled by the force of the ship but not enough to drag him right with it.

Astronaut Floats Over the Equator

The most popular incorrect response given by the students was that the astronaut should remain floating above the equator. The students choosing this response considered the astronaut to be stationary in space when he let go of the spacecraft. This coupled with the concept of zero or little gravity in space was felt by these students to justify the astronaut floating above the equator. For example:

> He will still be at the equator because he was not in motion when he let go and things like to go on doing what they were doing unless a force is imposed upon it to make it change. Since this is in space, there is no force so the man does not move.

and

> He will not move much. The pull of gravity at this height is not enough to bring him down.

In a few instances the astronaut was felt to be left behind because the spacecraft had some force to move it forward, whereas the astronaut did not. For example:

> He will be in the same place because there is no force moving him forward as there is to move the spaceship forward.

Astronaut Falls Towards the Earth

The numbers of students indicating that the astronaut would fall to the earth was found to be almost twice as prevalent in the students not planning to take high school physics (9.1%) as those students planning to take physics (4.9%). Most of these students held a conception that the astronaut would not be moving after letting go of the spacecraft. Thus, it was perceived that the astronaut would be pulled towards the earth by gravity. As some students wrote:

> Although the ship can push itself along to keep in orbit, the astronaut cannot. Therefore, he is floating downwards.

and

> The movement of the ship keeps it in orbit but the astronaut has no propulsion, so he would fall to the earth because of the pull of earth's gravity.

One student indicated that the astronaut could move either to the earth or away from the earth all depending on his height above the earth. This student wrote:

> It all depends on the height of the orbit. If too close to earth, gravity will pull him down to burn up in the atmosphere. If too far, he will stay in the exact same place, perhaps drifting toward the sun. (All of which is irrelevant, however, for only the stupidest spaceman would go out without a lifeline.)

Astronaut Drifts Away From the Earth

One response found to be very popular with the grade nine students (12.4%) was that the astronaut would drift outwards into space. Almost every student response indicated that in space there is no gravity and thus the astronaut should just float away. For example:

> There is no gravity out in space and the astronaut would float out into space because nothing would be pulling him towards the earth.

and

> Because you float in space.

Other Student Predictions

This question had the largest number of alternate responses of all the questions used in this study. Eight point two percent of the students left the question unanswered, and unusual responses such as orbiting the equator or drifting to the south pole were given.

Also found in this study were a number of responses indicating an answer similar to that of question #1. Once the astronaut let go of the spacecraft, he would be flung off in a range of paths similar to those predicted by the same students for the first question. For example:

> The astronaut would probably go in the same direction as the spaceship for the same reasons as the swinging ball before. The energy from the rotation will cause the astronaut to continue in the same direction as the spaceship heading north.

and

> Because of the circular motion, the man gets pushed outwards (like the ball on the string wants to go outwards) so it will go on a freefall outwards (sic).

Comparisons between Edmonton Student Responses and Other Studies

All student responses found by Lambert were observed in this study (Table XII). There were differences between the two studies, however, that need to be addressed. It was found that 37.7% of the students intending to take physics predicted the correct position of the

Table XII

Comparison of Grade Nine Edmonton Students Answers to Question #3 to Lambert's Study (1981)

Student Response	Lamberts Edmonton Study (1981)	Students Planning to Take Physics	General Grade Nine Student
Stays with Spacecraft	27.5% (N = 11)	37.7% (N = 69)	29.2% (N = 92)
Falls Behind in Orbit	22.5% (N = 9)	7.7% (N = 14)	8.6% (N = 27)
Remains at Equator	32.5% (N = 13)	18.6% (N = 34)	18.1% (N = 57)
Falls toward Earth	10.0% (N = 4)	4.9% (N = 9)	6.7% (N = 21)
Drifts Outwards from the Earth	5.0% (N = 2)	11.4% (N = 21)	12.4% (N = 39)
Other Responses	2.5% (N = 1)	19.7% (N = 36)	25.1% (N = 79)
Total Responses	(N = 40)	(N = 183)	(N = 315)

astronaut (although, in most cases, for the wrong reasons) as compared to 27.5% of the students already taking physics in Lambert's study. This difference could possibly be explained by the circular motion question (#1) used in this study and the resulting direction of student thinking. Lambert's study used linear concepts in previous questions.

In contrast to Lambert's study, where 22.5% of students indicated the astronaut should be trailing the spacecraft, this study had only 7.7% of students giving a like response (almost one third less). The student reasons supporting such a claim were found to be similar in both studies.

The numbers of students indicating that the astronaut should float at the equator were found to be more prevalent in Lambert's study. (32.5% as compared to the 18.6% found in this study). Also, the number of students indicating the astronaut should fall to the earth was 10% in Lambert's study and only 4.9% in this study.

What was found to be more prevalent in this study were the numbers of students indicating that the astronaut should drift outwards from the earth. This answer was given twice as frequently in this study (11.4%) than in Lambert's study (5.0%).

The numbers of "other" responses found in this study (19.7%) were significantly greater than those given by Lambert (2.5%). This appears to be explainable in part by the differences in methodology. Lambert's three dimensional presentation and interview structure would greatly reduce student confusion about the question. It was found that 8.2% of the students did not answer the question at all, and another 7.1% indicated that they were uncertain about the astronaut position. One

would expect that this group of students (15.3%) would have indicated a prediction of some sort if given the same question in an interview type setting.

All of the alternate conceptions uncovered by Lambert were also found in this study (described in the next section) except for her findings of different student conceptions of orbit.

Summary of Alternate Conceptions Found in Edmonton Student Study

There were a number of alternate conceptions used by the students in their answer to question #3. In fact, students were often found to be using two or more alternate conceptions in arriving at their prediction. It was surprising to find that most of the students making the correct prediction of the astronauts position did so through the use of alternate conceptions.

Student explanations for the predicted paths to this question were not as clearly answered as the other three (if answered at all). As a result, student responses were analysed to indicate shared conceptions between several students, but not tabulated to indicate percentages because of validation concerns.

The most common alternate conception used by Edmonton grade nine students was that there is no force or gravity in outer space. This conception was expressed by at least half of the students and was found in students making various predictions including the correct one.

Another very common student alternate conception that was found in most of the correct predictions was that of natural motion. Most

students felt the astronaut should continue to orbit as he had with the spacecraft because no forces would be acting on him, not even gravity.

That motion implies a force, even needs a force to continue moving was found in a large number of student responses. Students were found to use gravity and/or rocket engines to enable the spacecraft to move forward. The astronaut was perceived in a number of instances to remain floating somewhere because he had no force to keep him moving. Other examples of student work indicated that gravity would pull the astronaut down to the earth because he had no force to keep him in orbit.

There were a number of students who failed to conserve the astronaut's momentum: that is, they expected the astronaut to be left stationary in space as soon as he let go of the spacecraft. Student experiences such as the release of tissue paper from a moving automobile could be considered as supporting evidence. This is perhaps a primitive form of the "motion requires a force" conception.

There were a number of students that thought the rocket would create a vortex in space that would cause the astronaut to be pulled along with or behind the spacecraft. These responses resemble the situation where small objects are sucked into the draft of a larger moving object as it passes by.

Students were also found to consider gravity to be selective in its actions on the astronaut and spacecraft. In some cases gravity was thought to pull the spacecraft forwards, but not the astronaut. Other students thought that gravity would pull the astronaut forward too, but to a lesser extent because he was lighter than the spacecraft.

There were a number of less common alternate conceptions used by the Edmonton grade nine students. These include a concept of forward inertia of the astronaut that would carry the astronaut off at a tangent to release. The conception of a linear force in the direction of motion was also thought to be able to pull the astronaut tangentially. An erroneous concept of gravity in which all objects are pulled to the bottom of the earth (south pole), was mentioned by one student. More common was the conception that outside the earth, in the absence of gravity, objects would drift away. One last conception found to be present in some student responses was that of an object recoiling opposite to the direction of motion.

Teachers Predictions of Edmonton Student Responses

The teachers responded to question #3 with a number of responses (Table XIII). There were three main predictions, of which the most common was the correct one; that the astronaut would stay with the spacecraft. A total of 16 teachers felt that some of the students would choose this response. Two more teachers identified this as a possible response, but believed that none of the students would choose it.

One teacher stated that 100% of the students would choose this answer and thus none would get it correct. This teacher believed the correct answer would be that the astronaut would move in an orbit further out than the spacecraft's. In addition, two other teachers indicated different responses to be correct; neither of them gave the correct answer as a possible student response. One teacher believed that the astronaut would go forward from where he let go at the equator

Table XIII

Summary of Teacher's Predictions of Student Responses to Question #3

Predicted Student Responses	Teachers Choosing each Response	Mean of Teachers Predictions	Standard Deviation	Minimum and Maximum Predictions
With Spacecraft	18/20	42.8%	31.6%	0 - 100%
Falls Behind in Orbit	3/20	63.5%	47.4%	30 - 90%
At Equator	14/20	41.8%	22.6%	10 - 80%
Falls to Earth	7/20	33.3%	21.8%	5 - 70%
Drifts Outwards From the Earth	4/20	39.0%	48.5%	10 - 90%
<u>Other Responses</u>				
Tangential from Release Point	2/20	20.0%	14.1%	10 - 30%
Further out in Orbit over North Pole	1/20	0.0%	0.0%	0.0%
Forward a Bit Then Stops	1/20	0.0%	0.0%	0.0%
Unknown	2/20	6.5%	5.0%	3 - 10%

in the same orbit, before coming to a stop (Similar to the action of a water skier letting go of the tow rope behind a motorboat). The other teacher indicated that the astronaut should drift outwards away from the earth, where he let go.

Floating above the Equator

The most commonly predicted alternate response indicated by the teachers (70%) was that students would say that the astronaut would be left floating above the equator. Teachers perceived that this response would be chosen by 10% to 80% of physics 10 students. Only one of these teachers did not give any reasoning to support his belief that students would choose this response.

Six of these teachers indicated that a lack of watching and paying attention to shows or television programs involving astronauts moving in space was a possible source of this student response, whereas one teacher indicated that television programs causes it. For example:

> The majority of kids have seen enough television to realize; although if they look at some of the movies where guys get sucked out of the spacecraft they may get sucked into the idea that he is just going to disappear. The majority of the kids think he is just going to float with it.

One of the teachers thinking that the lack of paying attention to television stated:

> The rest are going to think, Aristotelian, I'm guessing, the ship is pulling him along, if he lets go he's left behind. I grew up I guess when you grew up, in the mercury, the Gemini and the Apollo days with space walks and so on and it was on the news every day even with my students just 10 years younger than me, I don't know, if they don't watch the news, never watch the news, it's not on now anymore, so they're not that familiar, well, I shouldn't say that because when the shuttle was going they had they're MU'S out and they did have some extra-vehicular activity but the

> students that I get seem to, not be aware of what is on the news. And with younger students, I would bet that they're even less aware of space travel, manned space travel these days.

The idea of the spacecraft pulling the astronaut along was shared by three other teachers. These other teachers also mentioned motors or engines to propel the spacecraft. Since the astronaut does not have his personal rocket, he would be left behind. As one teacher said:

> Fifty percent, or most of them, would think that the only reason that the spaceman is travelling in the space ship moving along inside is because the spaceship is propelling him along, as soon as he steps out there's no forces to move him forward, they're sort of told that in space there's no forces acting on them. So that if he got out, he would stay right there.

Another teacher stated:

> In their mind, they, even though the engines are not on and so on, they would associate the locomotion with the spaceship as opposed the man and even though the engines are not on and so on they would have this psychological thought it would proceed ahead.

Two teachers indicated that students might believe that forces would be exerted on the spacecraft and not on the astronaut. This hints at the concept of "no force ... no motion" and for one teacher the weightlessness of the astronaut could be evidence of no forces acting on him/her. For example, this teacher stated:

> Most of them have the idea that once you are in orbit there are no forces acting you, you are weightless. So that's why if he is working on the spaceship, then he lets go of it, somehow, even though its unreasonable the spaceship has no forces on it, but they think of him as not having any forces, so he is going to stay there. Even though the spaceship for some mystical reason goes to the north pole.

Five of these teachers stated that experiences on earth such as the observation of objects dropped from a moving automobile would be a

source of the student alternate response. For example, as one teacher felt:

> The other half would probably have thought that he'd be left behind sitting there. ... So I don't think they would have any problem. If we had a similar idea on earth, where a guy was driving in a car with an ejection seat and the car was going at a 100 kph, what would happen to him if he was fired upwards out of the car ... a lot of the students would say that the man in the ejection seat in the car, would stay where he was, because once they are out of the moving object they are stationary. That's it. The object's moving, fine, but once you are out of it, they tend to relate it to what's happens when they jump out of a car that's moving. They fall on their face because they strike the ground and what they say is, they think, I imagine they should be stationary. I think that's why they relate to what happens when that, you know, they know what happens when they fall off a skateboard or whatever. Skateboard stays moving and they are stationary.

Another teacher, relating the same event to the idea of a moving car said:

> Well it's just like jumping out of a car, you'd land flat on the ground and the car goes, and you'd stay behind. This is what they'd be thinking of. Thinking of the way we know it, the way it is on earth here. We base our experiences on what we know and this seems a little bit strange to be floating alongside the ship.

Falls to the Earth

The second most commonly predicted alternate response was that the astronaut would fall towards the earth if he let go of the spacecraft, was predicted by seven out of the 20 teachers. Four of these seven teachers felt that students would believe that gravity would pull the astronaut downwards. One of these four teachers felt that a failure by the students to realize that the astronaut was still in motion coupled with the influence of gravity would lead to a belief that the astronaut would plummet to the earth.

> Association of motion is strictly related to the lifeline. They would make the connection between that and gravity. And would therefore suggest that it is gravity that would cause the astronaut to be drawn towards the earth.

This teacher identified that some students believe that the motion of the astronaut depends on the spacecraft and his connection to it.

Another teacher (out of these four) felt that students would believe the spaceship was the agent holding him/her up. If the astronaut was not connected to or inside the spacecraft, then falling to the earth was inevitable. For example:

> Will realize (well I hope) that there possibly is a gravity out there so as soon as he lets go of the spaceship which somehow magically holds him up then "Boom" he starts falling to earth.

This notion of "the astronaut must be supported or he will fall" was clearly stated by one of the three remaining teachers from the seven. For example:

> Fall towards the earth, I think its that, ah, things fall. It's just inevitable, things fall from space. Astronauts, asteroids or satellites, or if you fall off a building. Personal experience. Things fall. Things unsupported fall.

Out of the remaining two teachers, one teacher was uncertain himself whether the astronaut would float or fall and the other teacher thought that students were misinterpreting the question thinking of a deterioration of orbit and an ultimate fall.

One teacher proposed and rejected the idea that the astronaut would fall towards the earth. This teacher felt that the concept of "no atmosphere, no gravity", would mean that objects in space would be above the atmosphere and thus experience no gravity. Therefore, the astronaut would not fall. For example:

> The third possibility is that they would say that he's crashed to earth, but I think that most people I've seen would tend to ignore that as a possibility because they associate, if they may have any inkling at all they associate mere orbit with weightlessness, not apparent weightlessness but weightlessness. And so they think that being out in space above the atmosphere in a vacuum; they associate vacuum and gravity or vacuum and weightlessness. He's well above the atmosphere, they seem to know there's an atmosphere, that space is a vacuum and once you're in a vacuum, that's it, you're weightless, so you wouldn't fall down, that's my belief, rightly or wrongly.

Drifts Outwards Into Space

Four out of the twenty teachers felt that at least some students would indicate that the astronaut would drift outwards into space. One of these teachers mentioned responses of tangential and radial outwards, thinking that students would refer to question #1 of the survey (the ball being rotated in a circle and released) in answering this question. Two of the four teachers held opposing views regarding the effect of television on their students. One felt that a lack of contact with good space programs and documentaries would be a source of student incorrect responses, whereas the other teacher felt that watching space movies or documentaries would be the source of incorrect responses. For example:

> Twenty five percent would not have any experience associated with satellite motion, they wouldn't have been to an IMAX movie, wouldn't have watched any movies perhaps or paid any attention to any movies and things like this and they can guess almost anything. ... They might think that the astronaut just sits there, just pushed himself away for the spacecraft, which is what has the motor on it, or what's propelling it, what might be deemed to propel it or something like this. Other possibility is that he is going to drift somewhere in space while the spacecraft drifts somewhere else because he's not attached to it.

The teacher who held an opposing view of television said:

> Most students, I would think their experience of it might have been watching television. And what normally happens on television when someone steps out of a (pause) one of the astronauts goes out for a spacewalk and the lifeline and they are moving away and move away from, they are sort of drifting away from the orbiting station. This astronaut would just drift away.

The remaining teacher of the four, was uncertain himself of what would happen. Eventually he felt that the astronaut would drift off into space, because the astronaut was outside the pull of the earth's gravity. This response and questions leading to his choice, represented what he felt the students would choose. To illustrate this:

> Because if it is orbiting in space and space doesn't have gravity, then the astronaut is just simply just going to drift into space. He won't fall towards the earth because he just doesn't have a gravitational pull. (If the astronaut would) fall to earth, there will be enough action due to the earth's gravity to pull him down, the gravity will be strong enough to pull him down. The students would ask the same question that I would ask ... Is the astronaut still in the earth's gravitational force? If it is in orbit, it has to be going at a fast enough speed to neglect the gravity.
>
> Question How far out do you think the earth's gravitational field goes? A little ways, a long ways, where does it end? Is there any marker that signifies where it starts to end?
>
> I don't think it ends, it decreases continually until a point where it is not noticeable.
>
> Question Where is the not noticeable point?
>
> Out of the earth's orbit. ... I am thinking of spacecrafts when they have to fire and they go into another orbit. ... When they fire into another orbit, then they are out of the earth's gravitational pull. If you are looking for a boundary, that's the boundary that I am thinking about. Once that happens things will experience weightlessness.

Trails Behind the Spacecraft

The belief that some students would have the astronaut trailing behind in space was given by only three of the 20 teachers. These three teachers predicted different sources for these student responses. One teacher mentioned that the students would be thinking of an engine that was attached to the spacecraft and not to the spaceman. The concept of motion would be given to the spacecraft even though the engine were shut off. For example:

> In their mind, they, even though the engines aren't on and so on, they would associate the locomotion with the spaceship as opposed the man, and even though the engines aren't on and so on they would have this psychological thought it would proceed ahead.

One of these three teachers felt that, since heavier objects appear to fall faster than lighter objects, some students might think the same in outer space. For example:

> Actually, maybe I should say quicker, anyway this spaceship is probably heavier and it will go a little faster.
>
> Question If its heavier, why do you think it would go faster?
>
> Well heavier things fall faster than lighter things.

The last of the three teachers that predicted that some students would say the astronaut would trail behind, attributed this response to watching space movies. Movies such as Star Wars and Dr. Who were mentioned as sources where astronauts in space were seen to float. The astronaut was perceived by this teacher to float only a little ways behind the spacecraft. As this teacher explained:

> I'd say 95% would now say that they will drag behind, they will be behind the spaceship but not by very much. So the guy is going to be left behind, but not by very much, ok,

> because they have seen too many "lost in space" things there. So the way I'll do this he is about here, a little way behind and I am not going to predict how much. A little way behind because they are going to think about the "lost in space" thing that's the vision they are going to have, I am convinced of it. But they are not going to be left a quarter of a world away.

Other Responses

The teachers gave few other responses than the correct answer and four alternatives. Two teachers felt that a small group of students would not have any idea of what the astronaut does and two others felt that a few students might give a tangential response. One teacher predicted that 90% of the students would believe that the astronaut would continue forwards in the orbit while coming to a stop, relating this to the motion of a water skier that drops the tow line from a motor boat.

Two responses were found to be most commonly identified by the teachers; that the astronaut will stay with the spacecraft and that the astronaut will stay at the equator. Only 15% of the teachers were found to have a rough idea of the numbers of students choosing the correct response and 5% had an idea of the numbers of students choosing the response where the astronaut floats above the equator. Over 67% of teachers appeared unaware of the existence of other common responses, such as falling to the earth, trailing behind the spacecraft and floating into outer space.

Comparison of the Edmonton Physics Teachers Predictions to Edmonton Student Study and Other Research

As illustrated in Table XIV, only the teachers predictions of the numbers of students believing that the astronaut would stay with the spacecraft could be considered an accurate reflection. In the five remaining catagories, the teachers' expectations varied from almost nine times to twice larger than uncovered in this study or half the actual. Comparison of the teacher predictions to Lamberts study yield similar overpredictions by nearly four thirds to almost eight times the actual.

As indicated above, most of the teachers were unaware of the majority of student responses.

Alternate Conceptions Summary

There were few teachers identifying alternate conceptions for this question. In many cases a student response was predicted but little or no explanation was given in support.

The most common of teachers predictions (made by seven) was that students would believe that a force would be necessary to maintain the orbital motion of the astronaut. It was felt that students would state the astronaut would stay behind in the absence of a force while the spacecraft would move forward because it had the engine or of a mystical reason. Some felt that the only reason the astronaut would move with the spacecraft was because a tether or lifeline would draw him/her along. Five other teachers felt that experiences on earth would give the student a conception that astronaut would be left behind. One of these teachers indicated that students predicting the correct position

Table XIV

Comparison of Physics Teachers Expectations of Question #3 to Grade Nine Edmonton Students and Lambert's Students (1981)

Student Response	Lamberts Study (1981) Grade Ten Physics Students	Edmonton Grade Nine Students Planning to take Physics	Edmonton Physics Teachers Prediction
Stays with Spacecraft	27.5% (N = 11)	37.7% (N = 69)	42.8% (N = 18)
Falls Behind in Orbit	22.5% (N = 9)	7.7% (N = 14)	63.5% (N = 3)
Remains at Equator	32.5% (N = 13)	18.6% (N = 34)	41.8% (N = 14)
Falls toward Earth	10.0% (N = 4)	4.9% (N = 9)	33.3% (N = 7)
Drifts Outwards from the Earth	5.0% (N = 2)	11.4% (N = 21)	39.0% (N = 4)
Other Responses	2.5% (N = 1)	19.7% (N = 36)	10.6% (N = 6)
Total Responses	(N = 40)	(N = 183)	

of the astronaut would also believe some force to act to move the astronaut forward.

Four teachers felt that some of their students would believe that there was no gravity in space. (One teacher, himself, believed this.) In all instances, the teachers indicated that students would believe there was a connection between atmosphere and gravity. If the student knew there was no atmosphere, this would indicate that there was no gravity.

Movies and television programs were believed by three teachers to give students a conception that objects float away in space. These teachers felt that the students would thus think that objects freed from any attachment to the spacecraft would be left behind and/or float outwards away from the earth.

Two teachers believed that some students held an alternate conception that unsupported objects would fall straight down. It was felt that the students would consider the spacecraft to be the agent supporting the astronaut. Once the astronaut breaks contact with the spacecraft, he also breaks contact with the support and should therefore fall.

There were a number of other alternate conceptions identified by individual teachers. All three of them were found in student usage, but not widely, with the exception of a conception of a coriolis force. One teacher believed that students would think the spacecraft would move faster in orbit because it was heavier than the astronaut. Another teacher felt that some students would believe that the astronaut's inertia would move him off in a tangential path once contact was broken

with the spacecraft. The last of these three teachers believed that students would think that the centrifugal or coriolis forces would cause the astronaut to spiral or drift outwards. (The concept of a coriolis effect on the astronauts motion was not found in any student response.)

The second most common student alternate conception, that of natural motion, was not found in any of the teachers' responses. The conception of natural motion suggests that in the absence of any forces, objects will continue moving the same way they were before. Students mentioned that since there were no forces or gravity in space, the astronaut should continue to do as he was before. This was found to lead a number of students to the correct response, albeit using the wrong conception.

Another alternate conception used by students was that the astronaut would be caught in the vortices behind the spacecraft and be dragged along after. This implies that the students believe that it is possible to create some disturbance in space (similar to the effect of air on light objects) that would affect the motion of other objects. Although the main conception used by students in this instance is that motion requires a force, none of the teachers identified a student belief in an "environment" in space where the passage of a larger object could totally dominate the motion of a lesser.

Two less common alternate conceptions found in student usage but not identified by any teachers was that gravity pulls all objects to the bottom of the earth, and that objects recoil in the opposite direction to each other. Both of these conceptions led a small number of students

to state that the astronaut would move towards the south pole upon release of the spacecraft.

Question #4

Edmonton Grade Nine Student Responses

Question #4 was the last question presented in both the student survey and the teacher interview. This question showed an astronaut standing on a flat lunar surface with a bent arm out to one side and a wrench slightly further outwards. The astronaut is described as gently letting go of the wrench and the students are shown a row of five different astronauts, with arrows drawn up, down, away and towards the astronaut, along with one more showing no arrows. The students are asked to identify which drawing best shows the direction of the force on the wrench.

The desired answer is that the net force acting on the wrench is towards the lunar surface due to the gravitational attraction between the moon and the wrench. While it was not expected, from available research, that many students would give such an answer, it was hoped that most would state the wrench would experience a force towards the surface, with a few students indicating that the gravity on the moon was 1/6th the earth's gravity.

Thirty seven point two percent of the students indicating an intention to take physics felt the net force on the wrench would be downwards. This value was almost 20% higher than that of the students not intending to take physics (See Table XV).

Student responses for the net force directed downwards were generally quite clear, with a large number indicating the relative

Table XV

Summary of Grade Nine Edmonton Students Answers to Question #4

Student Response	Students not Planning to Take Physics	Students Planning to Take Physics	General Grade Science Student
Away From Astronaut	12.9% (N = 17)	12.6% (N = 23)	12.7% (N = 40)
Away From the Moon	28.8% (N = 38)	17.5% (N = 32)	22.2% (N = 70)
Floats (No Force)	31.8% (N = 42)	27.9% (N = 51)	29.5% (N = 93)
Towards The Astronaut	0.8% (N = 1)	1.6% (N = 3)	1.3% (N = 4)
* Towards Moon's Surface	17.4% (N = 23)	37.2% (N = 68)	28.9% (N = 91)
Other Responses	8.3% (N = 11)	3.3% (N = 6)	5.4% (N = 17)
Total Responses	(N = 132)	(N = 183)	(N = 315)

strength of the lunar gravity in comparison to the earth's. Some common student responses were:

> The wrench will be pulled down because the moon's gravity is 1/6 of the earth's gravity ...

and

> There is some gravity on the moon, not much but enough to make the wrench fall.

There were a few instances of students answering correctly but giving incorrect reasoning. For example:

> The force is at the bottom of the wrench because there is hardly any gravity on the moon, so the force on the bottom will push the wrench up.

and

> There still is gravity on the moon and because nothing weighs anything in space, the wrench should go down.

The most common response made by the grade nine students was that the wrench would experience no force. This was given by 29.5% of the grade nine students, with more of the students not planning to take physics than students intending to take physics answering this way.

The most common of reasons given by students in support of such a choice was that there is no gravity on the moon, thus no force would be exerted on the wrench. For instance:

> There is no gravity on the moon so there is no force.

and

> There is no gravity on the moon and the wrench would stay in the same place.

Some students indicated that the moon was in space and there is no gravity in space. Thus, it was common to find student responses such as:

> In space there is no gravity so all it will do is float aimlessly.

and another indicated

> There is no air pressure in space and so no force.

There were a few other students that said that there was no force acting on the wrench because the astronaut had given it no force. For instance:

> It floats slowly, but it would most likely stay there until someone put some force to it.

Other students indicated that since the objects are weightless in space, there must be no forces acting on them. For example:

> The wrench is weightless in space.

A very common response was that the force on the object would be upwards. Twenty two point two percent of the grade nine students answered in this manner; a 10% difference was found between students not intending to take physics (28.8%) and those students intending to take physics (17.5%).

The most common student explanation for this was that the object would experience a force upwards because there was no gravity on the moon and objects would float upwards in the absence of such. For example:

> Up because there is no gravity to keep it down. It's automatic force is to float up. (The wrench has little weight).

and

> Because there is no gravity so it will automatically fly up in the air.

It was interesting to see a number of students indicate that since the moon's gravity was zero or non-existent, other bodies in space such as the earth could pull the wrench away from the lunar surface. For example:

> The reason for this is the gravitational force from the earth is acting on the wrench just the way the moon stays in orbit to the earth.

and

> Because there is no real force from the moon, but it will be pulled towards the sun.

One student even stated that almost anything in space would have enough gravity to pull the object off the moon's surface:

> Because there may be an effect of gravity through a certain object out in space such as probably a meteor or another planet.

There were also a number of students that indicated that some force upwards was stronger than the force of gravity downwards (or zero gravity) and so the wrench would float upwards (one student mentioned a floating force).

Some students indicated that the wrench would float upwards because the moon's gravity was too weak to hold the wrench. For example:

> On the moon the gravitational push is very low so things go upwards.

and

> The moon has much less gravity so the wrench would float slowly upwards due to less gravitational pull.

There were a number of instances where the wrench being lighter or of less mass was the reason it would float in the lower gravity environment on the lunar surface. For instance:

> Because there isn't much gravity and the wrench is lighter than a person, so it will go higher.

and

> Depending on the mass of the wrench, it could have various effects. Best assuming the mass is low, it would probably float up.

Such a conception could be drawn in part from everyday experience where objects float at a certain height in air (hot air balloon or helium balloon) or a depth (submarine or other objects visibly floating below the surface). This is similar to the Aristotelian conception of everything having it's natural place depending on it's composition of the four elements earth, water, air and fire.

Only two students used as their reasoning "because we saw it on TV" and two others indicated that the wrench was lighter than the astronaut.

Another fairly common response by the grade nine students was that the wrench would experience a force away from the astronaut. This alternative was chosen by 12.7% of the students.

About half of these students indicated that the astronaut must have given it a push when he/she released it. For instance:

> I think that the wrench will float away in the direction indicated above because that was the last direction in which it was held/ pushed/ used last.

and

> When your hand opens it sort of expands or pushes out at the palm and this would push the wrench sort of out.

Almost all of the other students indicating the force to be away from the astronaut presented reasoning involving the wrench already moving away from the astronaut, so therefore, there must be a force away. For example:

> There is little gravity on the moon, so it couldn't go down. But there is some force because when let go, the wrench moves away from the man.

Only four out of 315 students chose the last response available to the students where the net force was directed towards the astronaut. Each student response varied and no common reasoning was evident.

Comparisons Between Edmonton Student Responses and Other Studies

It appears that the Edmonton grade nine students are slightly more aware of the existence of lunar gravity than their counterparts in London or the younger Italian students (see Table XVI). Although percentages given do not allow for a direct comparison between the groups, inferences indicate the Edmonton students have a better grasp of gravity on the moon. The reasons for such a difference might stem from instruction, since most grade nine science teachers indicated that they had just finished an astronomy unit.

What all studies had in common, was that over half the students indicated the wrench would either float or move away from the moon. The group of students indicating a desire to take high school physics possessed the least number of these responses.

What was unexpected (and not found in the other studies) was the large number of Edmonton grade nine students believing the net force acting on the wrench must be away from the astronaut (almost 13%). These students felt that the astronaut would somehow push the wrench away when he released it. This fits nicely in the "force implies a motion" concept and was described as such by a large number of students.

Table XVI

Comparison of Grade Nine Edmonton Students Answers to Question #4 to Those of Watts and Zylbersztajn Study (1981) and Ruggiero et al Study (1985)

Student Response	Watts and Zylbersztajn London Study (1981)	Edmonton Students Planning to Take Physics	Edmonton Grade Nine Science Students	Ruggiero et al. Italian Study (1985)
Away From Astronaut		12.6%	12.7%	
Away From the Moon	Almost 80%	17.5%	22.2%	55% to 95%
Floats (No Force)		27.9%	29.5%	
Towards The Astronaut		1.6%	1.3%	
*Towards Moon's Surface		37.2%	28.9%	5% to 45%
Other Responses		3.3%	5.4%	
Total Responses	(N = 125)	(N = 183)	(N = 315)	(N = 40)

The Rugiero et al. Study (1985) indicated 55% of the students felt the wrench would float and 5% felt the wrench would fall due to the moon's gravity. The remaining 45% felt Natural Motion would cause the wrench to fall, but indicated uncertainty if Natural Motion would exist off the earth's surface.

One can almost extrapolate from these student explanations that gravity was not considered to exist or have much effect on the wrench.

Summary of Alternate Conceptions Found in Edmonton Student Study

There were a number of alternate conceptions identified in the written responses of the Edmonton grade nine students in answering question #4. Of these conceptions two accounted for the majority of all student responses.

The most common of all conceptions was that where there is no air, there is no gravity. Student who use this concept would hold the idea that since there is no air on the moon's surface, there must be no gravity. This resulted in the students making a number of different choices depending on the other conceptions held. The majority of the students stating that the wrench either floats, moves upwards or away from the astronaut, used this alternate conception.

The next most common conception found to be used by students was that the net force was downwards due to the moon's gravity. Many students indicated the strength to be 1/6 th of the earth's and that the wrench would fall more slowly on the moon than on the earth. It was surprising to read the student responses as they described characteristics other students used to support alternate conceptions. Most common were statements of the type "Even though the moon has no air, it still has gravity" and "even though the moon is in space it still has gravity". Statements such as these show the existence of a previous conception in the students mind.

Almost 10% of students, held a conception of the moon's gravity being too weak to hold the wrench down. With most of these students, a tug of war of forces between the earth (sometimes the sun or other large bodies in space) and the moon was mentioned. In most of these cases, the students believed the earth's gravity to be stronger than the moon's, resulting in the wrench being attracted to the earth. In other instances the force on the wrench was perceived to be in the same direction as the motion of the moon in orbit.

A number of students inferred or stated that the force was in the direction of motion. It was felt that the astronaut must have given the wrench a force sideways, with some indicating the sideways displacement between the astronaut and the wrench as evidence of a motion and thus a force.

Objects that are weightless are such because no gravity is perceived to be acting on the object. (For some students, weight and gravity were different). In space objects are perceived to be weightless (and float) and therefore gravity is not felt to be present. There was a small percentage of students who believed that since the moon is in space the wrench was weightless. Therefore, the moon was discarded as having any possible effect on the wrench.

One of the less common alternate conceptions was that gravity forces the wrench to go upwards. This conception was sometimes found in combination with weight, where the object's weight was perceived to pull the object downwards. Thus lighter objects such as the wrench might be too light to be held down whereas the heavier objects such as the astronaut could be held down.

There were other alternate conceptions used by Edmonton students, such as objects floating upwards and away in the absence of gravity. Only a few students stated that television programs showed them what objects on the moon do.

Teachers Predictions of Edmonton Student Responses

The physics teachers' predictions of their grade 10 physics student's answers indicates almost a total lack of awareness of what their students are thinking about lunar and space based phenomena. There were four alternatives identified by the teachers that some students were expected to choose (Table XVII). The teachers on average felt that around 75% of the students would choose the correct answer (the wrench experiencing a net force downwards). Only three teachers felt that less than 60% of the students would choose the correct answer (this includes one teacher who believed that the wrench would float if released by the astronaut). Several teachers expressed the feeling that it is difficult to imagine any student getting this wrong, and only one teacher felt that no student would choose the correct answer.

No Force

The most common alternate response (indicated by the teachers) expected from the students was that the wrench would experience no force and would float. Eleven of the 20 physics teachers indicated that some of the students should choose this response, and the overall average of all 20 teachers was that 10.6% of the students would say the wrench floats.

Table XVII

Summary of Teacher's Predictions of Student Responses to Question #4

Predicted Student Responses	Teachers Choosing each Response	Mean of Teachers Predictions	Standard Deviation	Minimum and Maximum Predictions
Away from Astronaut	6/20	7.0%	13.4%	0 - 50%
Away from the Moon	6/20	6.0%	15.2%	0 - 65%
Floats (No Force)	11/20	10.6%	15.5%	0 - 65%
Towards Astronaut	1/20	0.3%	1.1%	0 - 5%
Towards the Moon's Surface	20/20	73.5%	29.0%	0 - 100%
Other Responses				
No Idea	5/20	11.0%	5.5%	5 - 20%

Note: The value of the teachers choosing each response indicates only those teachers assigning a percentage other than 0.0%. The mean of the teachers predictions uses all values, including those teachers who assigned 0.0% to a value. The mean for the other response, includes only the five teachers who predicted some value for the students not having any idea.

Four of the eleven teachers felt that a concept of no gravity on the moon's surface would be a source for such an alternate response. One of these four felt that students might forget for an instant that there is gravity on the moon and another thought some students might think there is no gravity on the moon (no reasons given from this teacher). Of the other two, one teacher (holding an alternate conception) believed that gravity was too weak to hold the wrench down, whereas the astronaut was heavy enough to be held down and the last teacher felt some students might say the wrench floats because it is in outer space and things float in outer space. For example:

> If they thought there was no gravity, they know what gravity is, it pulls you down, they know that, if they thought there was no gravity on the moon, I can't see them not knowing that though, then I suppose if they don't know there's gravity on the moon, they'd choose that, because its out, out in outer space. So, therefore, things float in outer space.

The concept of floating was mentioned by three different teachers of the group of 11 as being the source of the "no force" response by the grade nine students. None of these teachers mentioned the concept of no gravity on the moon, and all felt that television programs would be the source of this response. One of these three felt that students would be mentally using a picture of some objects floating inside a spacecraft cabin, and the other two felt the concept of the moon being in space, or the astronaut pictured in a spacesuit in space would cause them to think things float in space. As one of these teachers stated:

> Looking at somebody inside a spaceship or whatever and noticing that when he lets go of his pencil it just sort of hangs there. Now you are on the moon but that is space, that's not being in a space ship, so I would think that's just an extension of what they have seen about people

> wearing spacesuits. A guy on the earth would never come up with that one in a million years.
>
> Interviewer reminds the teacher that the astronaut is on the moon.
>
> I know, but the moon is in space.

Another of these eleven teachers felt that television was again the main source of this alternate response because students seeing weightless objects floating in space while orbiting the earth might also believe that since the moon is orbiting the earth, the same conditions of weightlessness would exist on the moon's surface. For example:

> If a few students might guess, of course, because they have seen weightless environment they might think that on the lunar surface you have the same thing as a weightless orbit. They have seen astronauts set their spaghetti dinner up there, you know, and just reach up grab it whenever.

One of the remaining group of eleven teachers had asked students similar questions about the moon and gravity. His response indicated several different reasons that might direct the student to make such a choice. He stated:

> Automatically they think that as soon as you get out into space there is no forces, whether you are on the moon or not that is still off earth and it's off a major planet, and since the moon has no air they would sort of equate that with no force either. ... When we do Newtons laws, we talk about weight, and I ask them exactly that question, "How many would think that when you are close to the surface of the moon, maybe not right on it, but close to the surface of the moon, that you have some weight, and about half of them say, or maybe not half of them, but a quarter of them say, well, you are in space so you are weightless. Somehow they anticipate that if you have no atmosphere and you are not really on a planet, that if you are on an asteroid or a moon which is not really a planet, then all of a sudden then that is space and so you are weightless.

Force is Upwards Away from the Moon

Six teachers felt that some of their students would say that the wrench would float upwards (teachers predictions ranged from 5% to 65%). Five of these six teachers explained their choices, giving in total four different reasons. Two teachers felt that a conception of the object floating on the moon would give rise to this student response. This concept of an object floating would give the impression of it floating away, thus the force would be directed upwards. For example:

> Again, this one here, thinking about the movies they saw on space capsule, etc. and something is pushed away, well, maybe they might think it was pushed up and then it keeps going. ... it floats away, not realizing that the moon has it's own force.

One of these five teachers felt that some students would perceive that the earth's gravity would pull the wrench away from the moon. For example:

> Shear Guess. Some of them might think that it escapes and is gravitationally pulled to the earth because the earth, after all, gravitationally pulls the moon.

One of the these teachers felt that the concept of no air and a natural(?) buoyancy acting on objects would lead some students to expect that some upwards force acted on the object. For instance:

> Forgetting for one moment that there is no atmosphere on the moon, they would in turn associate the idea of buoyancy, perhaps acting on the object, therefore, there would be an upward component.

The last of these five teachers felt that this student response might result as a psychological desire to see objects float upwards away from the moon, because the moon is exotic and the student would want to see something exotic. As this teacher stated:

> Again relating it to what they have seen about space travel. ... Thinking would be selective. Perhaps somebody would think that I am in space and I let go of something, where do things go in space. I am just guessing wildly because I think every now and again in some of these things you in fact see that stuff starts to move. You want it to move. You don't want it to move down, that's common as borsch, and if it moves this way, away from you. But if it could, gently float up, that's great. So perhaps its getting a bit of misinformation in that situation.

Force is Away from the Astronaut

Six of the 20 teachers felt that some of their students would choose this response (These teachers predictions ranged from 10 to 50%). Three of these teachers felt that students would think that the astronaut must have pushed the wrench in dropping it. (One of these felt the kinked elbow drawn on the astronaut would lead students into thinking a push must have happened). For example:

> Strictly associated with a false understanding of the kinked elbow. The arm looks kinked and for that particular reason there would be some students that would think that you are pushing it sideways.

Two of these six teachers felt that, if students felt that the moon's gravity was slight or non-existent then watching television shows where objects float away from the side of the astronaut would lead them to expect that on the moon, objects might also float off to one side. As one teacher stated:

> I guess that 5-10% here would say that it floats off laterally, okay. Here again, they've been watching these space movies and you got a guy and, you know you watch the astronauts and you know, they have their pencil there, "Oh yeah,, I need my pencil" and they pick it out of the air, okay so, it's exactly the same thing. They don't equate moon as having gravitational effect that's measurable.

The last of these six teachers felt that some students would say the force is directed away from the astronaut due to misinterpretation of the question.

Other Responses

Only one teacher felt that some of the students (5%) would say that the force on the wrench would be directed toward the astronaut. This teacher explained this as a perceived attraction between objects, thus the wrench would be attracted back to the astronaut.

Five of the twenty teachers felt that a small percentage of students (between 5 to 20%) would have no idea and would guess any of the responses or leave it unanswered.

Comparison of Edmonton Physics Teachers Predictions to the Edmonton Student Study and Other Research

On the average, it appears that the Edmonton high school physics teachers have little idea of what their introductory physics students understand about space (Table XVIII). It was expected by the majority of teachers that students would be aware of a lunar surface gravity that is capable of attracting even small objects, such as the wrench. This expectation of their students was almost double what was found in the Edmonton grade nine students (73.5% expected, 37.3% found) and almost four times as was found in the Watts and Zylbersztajn study (20% or less). Almost half of the teachers expected 90% or more of their students to get the correct answer. Most of these teachers expected there would be no misunderstanding of the effect of gravity on the moon.

Table XVIII

Comparison of Edmonton Physics Teacher's Predictions of Grade Nine Edmonton Students Answers to Question #4 to Those of Watts and Zylbersztajn Study (1981), Grade Nine Edmonton Students and Ruggiero et al Study (1985)

Student Response	Watts and Zylbersztajn London Study (1981)	Edmonton Students Planning to Take Physics	Ruggiero et al. Italian Study (1985)	Edmonton Physics Teachers Prediction
Away From Astronaut		12.6%		7.0%
Away From the Moon	Almost 80%	17.5%	55% to 95%	6.0%
Floats (No Force)		27.9%		10.6%
Towards The Astronaut		1.6%		0.3%
Towards Moon's Surface		37.2%	5% to 45%	73.5%
Other Responses		3.3%		11.0%
Total Responses	(N = 125)	(N = 183)	(N = 40)	

The Rugiero et al. Study (1985) indicated 55% of the students felt the wrench would float and 5% felt the wrench would fall due to the moon's gravity. The remaining 45% felt Natural Motion would cause the wrench to fall, but indicated uncertainty if Natural Motion would exist off the earth's surface.

The 11.0% average for other responses for the teachers is the average of onlt the the 5 teachers indicating such a response.

(This compares to the 60 to 80% of the students thinking the wrench would experience no force towards the moon).

The most common erroneous response predicted by the teachers was that a number of students might say the wrench floats (predicted 10.6%). This prediction was found to be almost 1/3 of the actual number of students stating this (found 27.9% but could be as high as almost 40% because most of the students expecting the wrench to move away from the astronaut also indicated it floated). Only one teacher expected that more than 30% of the students would expect the wrench to float.

The belief that the wrench would experience a force away from the astronaut was held by 12.6% of the grade nine students intending to take physics, and predicted by 7.0% of the teachers. Comments from the six teachers involved a prediction that students choosing this response would think the astronaut had pushed the wrench. The student comments showed half actually making a similar inference, with most of the remainder indicating that the displacement of the wrench from the astronaut was evidence that the wrench must have been pushed.

Almost 18% of the students believed that the wrench would float upwards away from the moon. Only six teachers expected that any of the students might say this and the average of the teacher predictions was 6.0%.

Alternate Conceptions Summary

All of the alternate conceptions found in the Edmonton grade nine student survey were identified by the Edmonton physics teachers.

However, each alternate conception was only identified by a small number of teachers (less than 20%).

The most common student alternate conception that where there is no air, there is no gravity was expected by only one teacher. The most common alternate conception identified by the teachers (four) was that in space objects float and are weightless. This would give the student the perception that in space there is no gravity and since the moon was in space, no gravity should be there. Four teachers identified the student conception, that in the absence of gravity objects would float upwards.

One common alternate conception used by a number of students was that the astronaut must have given the wrench a force to the side. Of the six teachers who identified students choosing such a response only one felt that astronaut would give a force to the wrench.

Among the alternate conceptions identified by only one of the teachers were that the earths gravity might be strong enough to pull objects away from the lunar surface and that the moons gravity was too weak to hold the wrench but strong enough to hold the astronaut down.

There were six different teachers who felt that space programs and movies would cause a certain number of alternate conceptions to be held. However only 2 students out of 315, stated as evidence a television program for an incorrect prediction of an event on the moon.

Over all most of the teachers felt that a majority of students would believe that the wrench would be attracted to the surface because of gravity. Teachers awareness about possible student alternate conceptions used in solving this question were found to be minimal.

Chapter 6

Teaching Strategies

Review of the Literature

Introduction

One of the challenges facing today's researchers is to develop strategies for teachers' use in trying to overcome student alternate conceptions. The observed tenacity of these alternate conceptions over different age groups, before and after instruction, and their presence in some educators teaching such concepts to students, highlights the need for the discovery of effective strategies.

Failure to induce conceptual change has been observed in a number of cases where excellent teachers were using a variety of different teaching strategies (Anderson and Smith, 1985). In studying these different teachers (N = 14), the researchers found a common trait in all of their instructional strategies; the teachers failed to create conceptual conflict between the students' alternate conceptions and the desired conception.

Conceptual Conflict and Exchange

Mitchell and Baird (1986) have had frequent success in the restructuring of student physics conceptions to be closer to the desired Newtonian conceptions by using a process of "conceptual conflict." In this method, the teacher delays the introduction of the correct

conception. Events are set up in class and students are asked to predict the outcome using their conceptions. Mitchell and Baird have found the greatest success in students whose own alternate conceptions have failed miserably in predicting the outcome. White (1987) believes this to be a most crucial task for the teacher; to get the students to reflect upon their personal conceptions. It was found to be important for the desired conceptions to correctly predict the outcome without having to add extra conceptions and/or information.

That such a stategy works should come as no surprise. Four years prior to the Mitchell and Baird work, Posner, Strike, Hewson and Gertzog (1982) outlined a number of conditions they felt were needed to convince a student that their conceptions were not satisfactory and should be replaced. It was seen to be important to create dissatisfaction with their existing conceptions, then allow students to witness events where the results came into direct conflict with explanations derived from their conceptions. This is the most difficult task facing teachers (White, 1987) as unless a situation is set up in which students can try to predict the outcome of events, instruction will be less effective. (Mitchell and Baird, 1986) Such failure due to a lack of conflict is expected by White (1987), as students have often been found to believe opposing concepts, using them selectively in different settings.

Posner, Strike, Hewson and Gertzog (1982) outlined three characteristics of any replacement conception. First, it should be intelligible so that the students are able to apply the concept easily to the event in explaining it. It is felt that the gap between conceptions should not be too extensive, in order to minimize the danger

of students using the teacher's concepts inside the school whilst retaining their previous conceptions outside the school (Gilbert, Watts and Osborne, 1982, West and Pines, 1984, White, 1987).

The second trait of the replacement conception is that it must appear initially plausible and consistent with aspects of other knowledge held by students. It is important that this new strategy has the capacity to solve problems that were incorrectly dealt with by the previous concept. Thus, it becomes crucial for teachers to present students with situations which demonstrate the "fruitfulness" of the replacement conception (Brouwer, 1988).

The last trait mentioned by Posner, Strike, Hewson and Gertzog (1982) is that the replacement conception must be generalizable to other situations. This implies that teachers should assist and help the students apply the replacement concept to familiar and new situations (Brouwer, 1988). The importance of this has been stressed by Gunstone and White (1981) and White (1987) who have demonstrated that concepts can be compartmentalized as knowledge to be used in the classroom, without necessarily abandoning the initial concept.

In many ways, Posner's et al (1982) theory of conceptual change draws from the work of four science philosophers: Kuhn (1970), Lakatos (1970) and Toulmin (1972), Hashweh (1986). Scientific progress, as conceptualized by Kuhn, enters into time periods where the prevailing scientific theories fail to explain more and more of research findings. The failure of one or more theories rocks the guiding paradigms of the scientific community, resulting in a scientific revolution. This accelerates the development of a number of theories, with one eventually

rising to the top due to its superiority. The characteristics of the superior theory are believed by Posner et al (1982) to bring about conceptual change in students as well.

One of the problems with Posner's et al (1982) proposal for accomodating conceptual change in students involves the derivation of Posner's model from physics history which deals with well articualted, distinctive concepts (Stenhouse, 1986). The students, however, bring to the classroom numerous alternate conceptions, in various levels of articulation. Stenhouse (1986) stresses the problem of teachers dismissing students' alternate conceptions due to a lack of ability on the students' part to articulate them, and notes that teachers should be aware of the differences in language usage between themselves and their students.

Teaching Strategies

Posner, Strike, Hewson and Gertzog (1982) outline a number of teaching strategies that could aid teachers in inducing conceptual change in students. The researchers felt it important for teachers to develop lectures, demonstrations, problems and labs that could be used to create a conceptual conflict with the students' conceptions. Teachers were then encouraged to organize instruction, so as to diagnose student errors in thinking and to identify defensive moves used by students to resist conceptual change. Third, it was felt that teachers should develop successful strategies to deal with student errors and defensive moves. Posner et al, borrowing from Clement (1977), suggested that their fourth step would be to assist students to make sense of the

desired concepts by presenting in different modes and helping students translate the conceptions from mode to mode. Posner et al believed that the last part of the teaching strategy would be to develop evaluation techniques to track conceptual change in the students.

Posner, Strike, Hewson and Gertzog (1982) believe that the role of the teacher in helping to clarify ideas and present new information is not sufficient. They advocate a confrontational approach (in a Socratic sense) when students are having problems exchanging conceptions. The teacher should become a model of scientific thinking. This is taken to mean that the teacher should be ruthlessly consistent in dealing with beliefs, theories and empirical evidence, to be sceptical about "excessive ad hoc-ness" in theories and to develop a critical appreciation of the extent to which discrepant data still agrees with theory.

Brouwer (1984) has identified several elements in the Posner et al (1982) teaching strategy as having similarities to Piaget's Learning Cycle (AAPT, 1976). During the first phase of the learning cycle, Exploration, new situations would be presented to students, while allowing them to use their existing conceptions to try to understand them. In the Invention phase, it would be expected that students would be more receptive to the introduction of the currently accepted conception. The final phase, Application, would be used to present a multitude of different situations, thus allowing students to generalize the new conceptions.

West and Pines (1984) argue that the teaching strategies of a host of researchers (Erickson (1980), Nussbaum and Novik (1981), Posner,

Strike, Hewson and Gertzog (1982), and Champagne, Gunstone and Klopfer, (1983) can all be characterized into three stages; awareness, disequilibrium and reformation. The awareness phase represents the portion of instruction where the student is made aware of the shortcomings of their personal conceptions and of the existence of other competing conceptions. The disequilibrium phase is a period of instruction where anomalous events are presented to the students by the teacher to challenge the students' defense of their personal conceptions. The resolution phase is the period when the desired conception is introduced and is demonstrated to be superior to all other conceptions in its ability to explain all anomalies.

An even larger emphasis is placed upon identifying students' existing ideas about scientific concepts by Posner, Bell and Gilbert (1983) and Hewson and Hewson (1983). These researchers advocate the designing of curricula that build upon, rather than ignore, childrens' views. Finlay (1985) states that studies are needed to identify the prevalence and variance of student alternate conceptions arising in the most frequently taught content areas.

Some current researchers have called for the development of evaluation procedures that identify whether or not students have acquired the desired conceptions (Hewitt (1983) and Brouwer (1984)). Evaluative procedures exhibiting potential to fill such a requirement include the "interview about instance", "interview about events" process described by Osborne and Gilbert (1980) and Watts (1982). Diagnostic multiple choice tests, where all distractors are chosen from alternate conceptions as described by Halloun and Hestenes (1985) and

Treagust (1986) are also a possibility. Some authors advocate the use of multiple choice exams as a diagnostic tool (Treagust, 1986) because they are easy to administer and score. The interview format is time consuming and could pose some difficulties to the inexperienced interviewer but support for the interview can be demonstrated. It is argued that the interview is superior because it can illuminate the prevalence of alternate conceptions, provide deeper understanding of what the student knows and bring out what the student considers to be supporting evidence for his/her alternate conception. This would make a greater impact upon the unaware teacher. Most certainly, the multiple choice diagnostic exam would be the more efficient purveyor of information to the "alternate conception-aware" teacher.

Hewitt (1983) and Brouwer (1984) argue that students who are successful in numerical problem solving or knowledge based questions can fail to be internally consistent by holding both the alternate conception and the desired conception. Such a contention is supported by Gunstone and White (1981), Pines and West (1986) and White (1987) in their findings of students who compartmentalize instruction.

Hewson and Hewson (1983) outline a number of conditions under which students experience conceptual conflict, and ways they might use to determine which is superior. It is felt that the students must first understand what the two different conceptions mean, as a failure to understand either one implies that there will not be any conflict. A background of knowledge is necessary to provide a basis for comparison and promote a need for internal consistency. If students do not attain internal consistency, knowledge will remain compartmentalized, with the

students recalling conceptions according to the environment (eg. school conceptions and the real world conceptions). Internal consistency will eventually lead to a decision regarding the superiority of one or the other, thus leading to the rejection of the inferior one.

Posner, Strike, Hewson and Gertzog (1982) thus feel that the acceptance of a conception will be a gradual process. Terry and Jones (1986) support such a contention, stating that it will be a gradual and piecemeal process involving student modification of his/her ideas as the implications of the new concept become increasingly understood.

Concerns

Shuell (1987) expressed concern over teachers who leave the students with the impression that the scientists' conception is the "only" correct one. History has shown that there is value to previously discarded theories, as they have sometimes reappeared in "new" scientific breakthroughs. Shuell contends that it is healthy for a scientific field to be aware of other conceptions, their limitations and their strengths.

Conceptual conflict is seen as a necessary prerequisite to acieve conceptual exchange (Posner, Strike, Hewson and Hertzog (1982), Champagne, Gunstone, and Klopfer (1983), Anderson and Smith (1985), Hewson (1985), Pines and West (1986), Terry and Jones (1986), White (1987), Lawson (1988)). The failure to achieve conceptual conflict has been correlated with a failure in instruction to achieve conceptual exchange (Anderson and Smith (1985), Hewson (1985), White (1987).

Hewson (1985) identifies two different groups of researchers (Lawson and McDermott (McDermott (1984)) and Minstell (1982)) who have used the process of conceptual conflict with resulting successful conceptual exchange on the part of the students.

West and Pines (1984) however, contend that a considerable amount of conceptual development covering new material is necessary before conceptual exchange can occur, and state that Strike and Posner support this view. West and Pines (1984) also quote the findings of Champagne Gunstone and Klopfer (1983), where the Posner, Strike , Hewson and Gertzog (1982) teaching strategy was found to be successful with university students and unsuccessful with bright middle school students.

Anderson and Smith (1985) have modified the teaching materials to incorporate the Hewson et al (1982) teaching strategy with upper elementary and junior high school teachers, finding initial success. Their findings indicated that the teachers felt the new materials enhanced their own understanding of what they should be teaching and that many of them had learned more of the subject matter themselves. Teacher feedback to the students increased and students were asked more often to clarify ambiguous statements. Preliminary student results indicated an improvement of about 300% in student learning. (An increase from 35% to 81% in the number of students attaining the conception that our eyes detect reflected light and an increase from 10% to 33% of students understanding that our eyes detect the colors of light reflected from objects).

The success of the Hewson et al (1982) teaching strategy has not yet been firmly established. However, its popularity and continued

support among current researchers (Finlay (1985), Hewson (1985), Anderson (1986) Terry and Jones (1986), Hashweh (1986), Zietsman and Hewson (1986), Lawson (1988)) suggests that this strategy continues to dominate the others.

The Value of Science History

"We study history for the sake of light it can shed upon the problems of our own time." (Anonymous historian, World Book Encyclopedia).

Evidence exists to indicate that alternate conceptions strongly influenced the conceptions of the earlier scientists (McCloskey (1983), Brouwer and Singh (1983), Wandersee (1985)). Wandersee epistemologically addresses science history as a means to anticipate student alternate conceptions in specific content areas. Support for such a contention has been established by McCloskey (1983) and Wandersee (1985), in classroom studies of students, where strong similarities have been found between current student alternate conceptions and those that have been discarded by previous scientists.

As can be witnessed in this thesis, the different alternate conceptions of gravity used by Edmonton science students bear strong similarities to the most common historical conceptions of gravity as identified by Brouwer and Singh (1983). An updated summary of these, as provided by Brouwer (1988) are:

1. No force is required for bodies to fall. They simply return to their natural place (Aristotle, Empedocles).

2. The atmosphere (air) through which a body moves propels it downwards (Averroes).

3. An attractive force exists between all material bodies in the universe. Therefore, a ball, being attracted towards the earth, falls toward it. (Newton)

4. The rotation of the sun, moon and earth are responsible for causing bodies to fall towards them (Kepler, Descartes, Leibniz).

5. There is no basis for assuming the force of gravity to exist in outer space (Adams, in Great Britain in 1846 could not convince the Astronomer Royal to look for a new planet, Neptune, because the Astronomer Royal was not convinced that gravity extended to such great distances.)

6. Bodies are repelled by the heavenly spheres (St. Bonaventure.)

7. A heavenly body influences the space around it in such a way that a smaller object is thrust towards it (Bacon, Einstein?).

The comparison of the Brouwer and Singh (1983) and Brouwer (1988) historical conceptions to alternate conceptions found in the Edmonton grade nine student survey indicate the value of science history in developing science curricula. It is possible that a historical approach to science teaching might help students make more explicit their own alternative conceptions.

Results of the Edmonton Teacher Study

Edmonton High School Physics Teachers Teaching Strategies

The Posner et al. (1982) teaching strategy suggests that the teacher actively engages the students in testing out the different alternate conceptions, in order to demonstrate the superior conception. Events and demonstrations are to be carefully chosen so that alternate conceptions can be used to make a clear prediction of the outcome which

fails miserably. Researchers have found that failure to successfully challenge alternate conceptions through student predictions has lead to failure in achieving conceptual exchange. After conceptual exchange has occurred, it becomes important for the teacher to work on integration of the new conception with the students' knowledge, as failure in integration leads to compartmentalization. Although the success of the Posner et al. (1982) teaching strategy has not been conclusively demonstrated, growing evidence supports it, and its crucial areas are becoming more clearly defined.

The Edmonton high school physics teachers indicated that they would use four main teaching strategies when teaching these subject areas (those from which the questions were drawn) to their students. These four strategies (listed from most common to least) are; expository, demonstration, analogies and questioning with discussions. Of these four teaching methods, only analogies (Posner et al. 1982) has been indicated to be successful in dealing with alternate conceptions.

Expository teaching strategies accounted for almost half of the indicated teaching strategies. Most expository strategies were coupled with other strategies but there were a number of teachers who indicated just an expository approach. For example,

> What is causing the force? Just talk about it and make sure they understand its only gravity and gravity doesn't make things go up it pulls things towards the center of the earth.

It was most common to have teachers suggest an approach involving exposition combined with other strategies. For example:

> Ok, very simply, uh, I would say well, there's gravity on the moon, just like there is on the earth you know, any mass

> has, exerts a force, and therefore, all you do, set up, if I had a spanner here and let go it'll fall to the ground so why should it be different on the moon since you also have gravity on the moon . Any mass exerts a force on another mass and if you let go of a spanner here it'll fall towards the earth it won't just float or move away, so why should it be different on the moon. Now, they might not be convinced that masses exert force between each other but then you, you'd actually do, like , students could say, "Hey, prove that masses, you know, I don't believe masses exert force on each other." So therefore, then you'd have to do an experiment where you could, you know, you'd have to demonstrate that masses exert force on each other.

The majority of teachers suggested demonstrations as a preferred strategem for teaching at least one of the conceptual areas. An example of one used in the study of circular motion is:

> Oh yeh. I started spinning things around and we had a real barrage of objects flying around the room, bouncing off the walls and you know I was spinning them slowly and spinning them quickly. You know it's not exact because the effect of gravity throwing a curve into it, discount that and see what would happen. For the most part you could see, use large objects. They came across the room in a very straight pathway and that convinced them. I think that was the best way for that, they could actually see it happen. I have one or two students, they can actually see things happen and they still don't believe it and they'll argue to their death just about, real interesting people. Well it convinced almost all of them.

Less than 10% of the teachers indicated an approach involving questioning and discussion, such as the following example:

> I draw a force diagram on the board and I analyse it. What causes the object to go up. Is the force still acting that is causing the object to go up once it is released from the hand? I discuss this and draw the diagrams on the board to see well as show them physical motion of throwing an object up. To see whether the student can understand that the force that was acting from the hand has stopped the minute that you in turn release the ball. The only thing that could possibly be after that is the force of gravity that is acting on it. I then ask them what causes the object to slow down? What causes the object to come back down? What causes the object to accelerate on the way back down? So by asking pertinent questions in that particular regard I

clarify some of the difficulties that the student might have had.

Analogies and metaphors were described by Posner et al. 1982 as a means to suggest new ideas to students and to make them intelligible. In this context, the Edmonton high school physics teachers said that they would use analogies to present conceptually similar situations to the students and, thus, associate some of the student experiences to the desired conception.

Almost 85% of the analogies discussed with the teachers involved the two circular motion questions #1 and #3, with almost two thirds of these coming from teachers holding a B.Sc. in Physics (or equivalent). Although most of the analogies mentioned by the teachers tended to be brief, two of the more detailed are as follows:

> You just talk to them what happens if you ride a bike without a fender, without a mud guard and through a puddle. How can, you know, his back is when you're sitting up here, it gets wet. Why do stones fall off if you follow a gravel truck they hit the wind screen when the wheels are turning. So it suddenly comes up why does mud fly off the wheels, so I suppose some try to put something there that is practical. ... Well, I would suppose the argument they would say "how come when I am driving a car and suddenly I lose control, (they don't drive cars in junior high) or an icy street, I end up in the ditch." You see here's the road this way you were trying to go around the curve and you end up in the ditch. Well, you know you did move out, the fact you probably went this way, you know, at an angle into the ditch, the curve went and then you ended up in the ditch here doesn't probably occur to them. But you tangentially hit the ditch, and the fact there was a slope from the road to the ditch had something to do with it. I would say, yes that would probably be an argument you could use. I was on the road and ended up in the ditch.

and:

> If you have a cup of water and you punch a hole in the cup the water will stream out and they all know that. Why is the water going to stream out? Because of it's weight

> pushing it down they all know that, so, when you drop the cup what will happen, well, somebody always guesses, the water will stop leaking out, and they know what to watch for so I stand on the counter and drop it, and when they know what to watch for they see that it stops leaking on the way down, and so we talk about if you have a leaky cup or something, that's an easy way to fix it, just drop it. Then, I can see some lights coming on and some eyeballs clicking open and they realize that the water and the cup are falling together, and that's why there's no force between them, and the water doesn't leak, and then we talk about ships in orbit and it helps to bring it together. So those are the things that I do. Emphasis on atmosphere and gravity often comes up, and if it doesn't, I don't think I would mention it. I don't think it would come to me to mention it, to argue about atmosphere and gravity, but I've emphasized that it's force between masses, just leave it at that, just force between any two masses, and that in fact without it the ship would be travelling in space like this. They are falling together and, therefore, he should be over here, with the ship, as long as he doesn't push off, like the cup and the water, the two are falling together.

Hart (1987) outlines a sequence of student activities that also involve questioning and discussion, which evolved from Minstrell's (1982) question and discussion about related situations. Hart found that the questioning discussion strategy, by itself, was successful only about 50% of the time. That the researchers were aware of student alternate conceptions and thus were directing their questions towards the removal of such is significant, because one could logically expect such teachers to have the greatest chance of success.

Of the Edmonton high school physics teachers planning to use a strategy of questioning and discussion, only three indicated that they would direct their instruction at the alternate conceptions. One teacher indicated that he would question the consequences of the alternate conception, another would work out the implications and the third would simply target his questioning at the alternate conception.

Since at best, these teachers only indicated a strategy to deal with two alternate conceptions, one might expect only limited success.

Of the remaining strategies, only one stands out. One teacher recalls holding an alternate conception from childhood and having it shattered by experience. Although little has been written about the success of anecdotes, this one should be studied further. As this teacher explained his teaching strategy for question #1:

> It's a relatively difficult one to give them a nice demo... you can spin things around your head and cut the cord or something like that but I imagine things would happen too fast for that to be of any use. I like to use a little anecdote, because this particular thing happened to me when I was a kid. And I tell them this story, about the playground with the merry-go-round, the ones that you run around and push, my friend and I took a poplar pole and rammed it into this thing so instead of having a radius of maybe 4 - 5 feet, we had this thing like about 25 feet, and I got on the end. He started pushing that thing on the inside and of course I'm going about nineteen times as fast as he is on the inside, I'm way out on the end, and I decided that this is more than I could stand, so I decided I'd let go. Now at that point when I decided I would let go, I think I had the idea that nothing very much was going to happen to me that I would just sort of slow down, perhaps hit the ground, something like that. Whereas in actual fact, I went sailing straight out this way and landed up in a bush, OK I didn't go straight out, I didn't go in towards the center, I knew that when I let go I was heading towards this patch of bush and that's where I ended up. So it was like a revelation, I suddenly understood what would happen when you let go and you were travelling in a circular path. You move straight in the direction you're going. But again, that's anecdotal, it isn't necessarily confirmation, they might need something a little more concrete, at least some of them.

One final observation about the Edmonton high school teachers was that the greater the teachers awareness of student alternate conceptions, the more aware they were of their tenacity and difficulty

ridding students of them. As one of the most "alternate conception" aware teachers stated:

> Now, unfortunately, I never feel terribly successful about that: I wish I had some other ideas. Because, we can do all kinds of this stuff and then at the end of the unit I give them a question, and I say "Plot the speed-time graph of a ball thrown into the air." Well, they give me all kinds of things, nobody ever gets this. When I show them at the end of the test I get arguments; not just acceptance but arguments, resistance, so I know that, it's time to move on but we're certainly not finished our job here, but it's time to go on, anyway. And I get resistance, and the resistance comes from the most vocal students, of course but often the brighter ones, not the brightest I think they can catch it but the ones who are above mediocre and the top average or slightly better than average, they're the ones that have the difficulty. Now there may be just the problem here with the graphing because graphing is very abstract, and they may just have difficulty in relating the understanding of the motion, which may be correct, to the graphical interpretation, so they may get this and just not be able to express it, I'm not sure but I think one is fairly close to the other. That's all I can do about that, I can't break it.

Conclusion

There appears to be unaminous consent among alternate conception researchers, that the teacher must be aware of student alternate conceptions before he/she can successfully address them. It is felt important that the students actively participate in the classroom instruction by placing their conceptions open to challenge. Classroom demonstrations where alternate conceptions can predict an outcome and will fail miserably are felt to be successful. A clear, understandable correct conception should be available to the students (there is debate about when to present the correct conception to students) and the teachers should clearly demonstrate the superiority of it. The

presentation of phenomena related to the conception has also been shown to accelerate conceptual exchange.

Using the teaching strategies outlined by Edmonton teachers only limited success would be achieved. Even the teachers who indicated that instructional strategies should address the students' alternate conceptions might be expected to experience limited success (extrapolating from the limited succes of other "incomplete strategies" that have been presented in the literature as either support or criticism of the Posner et al. (1982) strategy).

The teachers did not indicate awareness of the teaching strategy research. This indicates that the research is not reaching the population for which it is intended.

Chapter 7

Summary Discussion and Implications

Problem

Student alternate conceptions have been found by researchers before, during and after high school physics instruction. The durability of these, even following "successful" instruction, is of great concern to international researchers.

In the past decade, the extent of the problem has been explored and common characteristics have been identified by research. This field is maturing, and it is imperative that teachers begin to implement the findings.

The problem facing the academic world is to design successful inservice programming to inform teachers about student alternate conception research and how it impacts upon their classroom environment.

Methodology

This thesis attempted to discern teacher awareness of their students' alternate conceptions, and teaching strategies used when encountering alternate conceptions in each of the addressed conceptual areas. In order to accomplish this, problems were drawn from the area of mechanics, where research has been extensive, and, thus, more complete.

Four questions were used in this thesis; two concerning circular motion and two concerning gravity and motion. These questions were

again split, so that one of each was terrestrial based and the other non-terrestrial. All four questions have been used in prior research studies. This allowed findings to be compared against an established body of research.

Twenty teachers were studied in the period from January through March 1988. Five questions were presented to the teachers (one was subsequently dropped, as it was judged to be outside the scope of an average high school program). They were asked to predict the various responses they expected students might give. Teachers were then asked to anticipate the reasons they believed students might choose the incorrect responses. This was followed by an inquiry about strategies they would use to teach the conceptual area from which the question was drawn.

Teachers who actually possessed alternate conceptions were questioned further to discern the nature of them. These questions took the general form of "Suppose you are faced with a student who has difficulty accepting your answer as correct, how would you explain yourself to convince the student?"

In order to more closely match populations of students and teachers, 315 junior high students (in the last month of grade nine) were asked to answer the same four questions and explain their answers. These students were chosen from a number of schools that feed into the high schools from which the teacher sample was drawn.

Findings and Conclusions

All raw data were analyzed in isolation from other research findings first, then compared to previous research. This ensured that as much information as possible was obtained, enhancing objectivity. For example, treating data in this manner allowed new information to be gleaned about student alternate conceptions.

Research Question #1: Do the Edmonton high school entry level students hold the same alternate conceptions that have been identified in previous research in the areas of force and gravity?

All alternate conceptions found in previous research also present in this Edmonton student survey in similar proportions with the following exceptions:

A. New alternate conceptions were identified that have not been discussed in previous research, mostly in the area of rotational mechanics.

B. Twice as many students planning to take physics were found holding a correct conception on questions based in space as those not intending to take physics.

C. Twice as many Edmonton grade nine students were aware of the existence of gravity pulling objects downwards on the moon as students from other countries (London 1981, Italy 1985?).

D. A large percentage of students could correctly predict the outcome of circular motion questions used in previous research through the use of alternate conceptions.

E. Students were often using a combination of two or more alternate conceptions to predict the outcome of different events. It was also found that a central alternate conception (i.e. force in a direction of motion) resulted in students formulating secondary conceptions (i.e. gravity acting only when the object falls).

Research Question #2: Are senior high school teachers of physics aware of student alternate conceptions in the conceptual areas of force and gravity?

The Edmonton senior high school physics teachers were relatively unaware of the alternate conceptions used by their students prior to instruction. They were least aware of gravitational alternate conceptions.

As a group they were able to identify almost every student alternate conception found in previous research and in this study. Individually, each identified only a few of the total number found in student answers to the four questions.

It was found that thirty percent of the teachers held one or more alternate conceptions themselves. It is likely that some of those alternate conceptions have been passed on to students, as they were related to phenomena commonly discussed during a high school physics course. Two teachers expressed frustration over the difficulty in ridding their students of what they perceived to be incorrect conceptions, which were in fact correct.

There were a number of instances where the teachers correctly identified responses found in the Edmonton student survey but not

mentioned by previous researchers. In all cases except one, the numbers of students choosing such responses were small. There were a few teacher predictions that were not found in any of the student responses.

Research Question #3: Do senior high school teachers of physics have teaching strategies to deal with student alternate conceptions, in the areas of force and gravity, that would be considered effective according to current research?

Teaching strategies proposed by the teachers fell into the following categories; expository (46.7%), demonstration (20.0%) of the desired conception, analogies (17.8%) and questioning with general discussion (8.9%). The percentage of teachers using analogies may be much higher as they tended to use common phenomena as support for their predictions of different student responses.

Teaching strategies proposed by the Edmonton senior high school physics teachers would all be classified (Posner et al, 1982) as unsuccessful in accomplishing conceptual exchange. Of the stages identified necessary for a successful teaching program (Posner et al, 1982), all teachers presented the conception they believed to be correct to the student with a few allowing the students to predict the outcome of some event, in an attempt to create dissatisfaction with their conception. None of the teachers stated any need to generalize the conceptions to other phenomena in order to prevent compartmentalization.

None of the teachers was aware of the current research in teaching strategies including the three who were aware of research into student alternate conceptions.

Suggestions for Future Research

Out of the problems studied in this thesis, a number of findings bear further research. They include the following:

1. Students who intended to take physics at high school were about twice as aware of the "correct" conceptions in space based questions as those who were not intending to study physics. However, on earth based questions, physics bound and non-physics bound students were not significantly different in their answers. It would be interesting to pursue student concepts of space, to find out what students find interesting (and what not) about physics, perhaps establishing some links between space knowledge and physics.

2. There were several new alternate conceptions identified, that have not shown up in previous research. In particular, a concept of spin associated to circular motion which resulted in the object spinning upon release was commonly believed by students. Also, a strong association with a "tug of war" situation between a string and ball had previously been described in student terms of centrifugal/centripetal forces. Edmonton students, however, used such words sparingly, but clearly held a "tug of war" conception, with the string being seen to snap inwards and the ball fall outwards. Those two findings deserve to be be addressed at some future time.

3. Students were able to predict the correct outcome of different questions by using alternate conceptions. The areas where students can correctly predict the outcome of some event, while still holding

alternate conceptions must be identified in the near future. Teachers need to be aware of different phenomena where the outcome can be predicted by alternate conceptions so instruction can be accordingly modified. Without such awareness and subsequent modification of instruction, students will continue to be able to keep their alternate conceptions with no conflict.

4. Several teachers possessed alternate conceptions themselves. Future research should look at characteristics of teachers who do and don't possess alternate conceptions. For example, the possession of a correct conceptual structure could be correlated with level of education, type of education (ie. physics versus other major), years of experience, degree of extra inservicing, etc. The outcome of such research might impact upon future teacher training.

5. Teachers could be studied for teaching strategies in all areas of physics. Powerful anecdotes and simple yet special demonstrations that profoundly affect the student are known by teachers. Individually, the teachers hold ideas that can enhance physics instruction a little. Collectively, the physics teachers possess a body of strategies that could alter the way teacher resource manuals would be written in the future.

6. The teachers were studied for their awareness of student alternate conceptions in the areas of mechanics only. The teachers should also be studied for their awareness of student alternate conceptions in other areas of physics as well as other academic areas.

7. There is a need to study students who have successfully exchanged alternate conceptions for the desired conception. It would be interesting to have students identify the events that led up to and eventually caused them to exchange conceptions. Such a study could provide information that would lead to more successful teaching strategies.

8. There is a need for research determining whether teacher awareness of student alternate conceptions leads to more effective teaching.

9. There is a need to determine if teacher usage of the Posner et al (1982) teaching strategy leads to more effective teaching.

10. The perceived importance that physics teachers place on student alternate conceptions should be addressed. If it is found that teachers who are aware of student alternate conceptions place little or no significance on them (as one of the three teachers who were aware of current research did), then their reasons for holding such beliefs should be found. Methods to make teachers more concerned about addressing student alternate conceptions during instruction should be developed. Alternatively, such research might find that too much curriculum is presently required to be taught for the teachers to successfully deal with alternate conceptions along with other priorities arising in the classroom.

11. It was surprising to hear a number of teachers state and/or imply that after instruction, the numbers of students holding alternate conceptions would be greatly reduced. A study should be conducted on

teachers correlating their perceived success rates with the actual. A teacher with a perception of high success with their instruction might be resistant to change. The findings of such a study could be of importance in motivating teachers to use alternate conception research findings (as presented in inservices) similar to the Posner et al (1982) teaching strategy, which found that the more the students' alternate conceptions were challenged through prediction of event outcomes, the more they were susceptible to conceptual exchange.

Recommendations

Given that Edmonton physics teachers have been found to be generally unaware of student alternate conceptions and totally unaware of recommended effective teaching strategies, it is felt that inservices should be given to these teachers on the above mentioned topics.

This study is descriptive in nature in an area where there has been little or no previous research. Its purpose was to illuminate areas that require further study. It is hoped that other researchers will address some of the issues raised by this study in the future.

Appendix 1

Teacher Predictions of Student Responses to Question #1

TEACHER CODE	TANGENTIAL	RADIAL OUT	CURVED	ANGLED FROM TANGENTIAL	RADIAL IN	CURVILINEAR	MISCELLANEOUS
A	* 80%	20%					
B	* 10%	75%					15% b
C	* 30%						70% c
D	* 35%	50%	10%		5%		
E	* 10%		70%	5%			15% e
F	50%			* 50%			
G	* 60%	10%	30%				
H	* 25%		75%				
I			70%			* 30%	
J	* 60%	35%	5%				
K	* 30%	20%					50% k
L	* 50%	30%		20%			
M	* 25%		50%	25%			
N	* 70%	30%					
O							100% o
P	* 20%	80%					
Q	* 20%	40%		40%			
R	* 5%	80%		15%			
S	* 0%	65%	10%	10%	15%		
T	* 25%	x%		x%	x%	x%	

* Indicates what the teacher believes to be the correct answer
x% Indicates that no percentage was estimated by the teacher

Miscellaneous:

b ... 15% curve towards the tangential
c ... 20% drop, 50% no idea
e ... 15% no idea
k ... 20% drop, 20% drawn straight from arrow, 10% curves toward tangential
o ... 50% drawn straight from arrow, 50% curves toward radial

Appendix 2

Teacher Predictions of Student Responses to Question #2

TEACHER CODE	UP NO DOWN	DOWN NO UP	UP DOWN DOWN	DOWN DOWN DOWN	DOWN NO DOWN
A	34.2%	0.0%	22.8%	* 5.7%	8.6%
B	45.0%	0.0%	15.0%	* 7.5%	22.5%
C	51.2%	0.0%	12.8%	* 0.0%	0.0%
D	0.0%	0.0%	9.4%	*28.1%	0.0%
E	* 100%	0.0%	0.0%	0.0%	0.0%
F	*19.2%	1.2%	38.4%	9.6%	4.8%
G	9.0%	4.5%	9.0%	* 4.5%	4.5%
H	100%	0.0%	0.0%	* 0.0%	0.0%
I	*44.8%	4.8%	11.2%	4.8%	19.2%
J	37.8%	0.0%	25.2%	* 3.6%	5.4%
K	6.0%	0.0%	14.0%	*49.0%	21.0%
L	100%	0.0%	0.0%	* 0.0%	0.0%
M	18.8%	0.0%	15.0%	* 7.5%	9.4%
N	10.8%	0.0%	25.2%	*31.5%	13.5%
O	*16.0%	0.0%	64.0%	16.0%	4.0%
P	* 4.8%	4.8%	1.6%	3.2%	9.6%
Q	* 6.0%	0.3%	30.2%	14.9%	3.0%
R	10.0%	0.0%	0.0%	* 0.0%	0.0%
S	33.3%	0.0%	16.7%	* 3.6%	7.1%
T	2.2%	0.4%	23.3%	*40.9%	3.9%

* Indicates what the teacher believes to be the correct answer

Note: A non-zero percentage does not indicate that the teacher has demonstrated awareness of an alternate response. These percentages were infered from other raw data that did not specifically identify these groups.

Appendix 3

Teacher Predictions of Student Responses to Question #3

TEACHER CODE	WITH SPACECRT	BEHIND IN ORBIT	AT EQUATOR	DRIFTS OUTWARDS FROM RELEASE	FALLS TO EARTH	MISCELLANEOUS
A	* 0%	97%				3% a
B	* 50%		50%			
C	* 20%				70%	10% c
D	* 15%		25%	10%	40%	10% d
E	100%					* e
F	* 70%		30%			
G	* 80%		20%			
H	* 50%		50%			
I			10%			* 90% i
J	* 70%	30%				
K	* X%	X%		X%	X%	
L	* 33%		67%			
M	* 30%		40%		30%	
N	* 80%		20%			
O				* 95%	5%	
P	* 20%		80%			
Q	* 30%		70%			
R	* 0%		50%		20%	30% r
S	* 5%		60%		35%	
T	* 75%		13%	12%		

* Indicates what the teacher believes to be the correct answer
x% Indicates that no percentage was estimated by the teacher

Miscellaneous:
a ... 3% unknown
c ... 10% unknown
d ... 10% tangential from point of release
e ... 0% believes the astronaut will be further out in orbit.
i ... 90% astronaut will go forward a bit before coming to a stop.
r ... 30% tangential from point of release

Appendix 4

Teacher Predictions of Student Responses to Question #4

TEACHER CODE	ASTRONAUT AWAY FROM	THE MOON AWAY FROM	FLOATS	ASTRONAUT TOWARDS	MOONS SURFACE TOWARDS THE	NO IDEA
A	10%		60%		* 30%	
B					* 95%	5%
C	20%	10%			* 70%	
D	10%	5%	25%		* 60%	
E	50%	25%	25%		* 0%	
F			10%		* 90%	
G		10%	10%		* 80%	
H					* 90%	10%
I			10%		* 90%	
J			1%		* 99%	
K	30%				* 70%	
L					* 100%	
M	20%				* 80%	
N					* 100%	
O		65%	* 25%		10%	
P			5%		* 95%	
Q					* 90%	10%
R					* 80%	20%
S		5%	30%	5%	* 60%	
T			10%		* 80%	10%

* Indicates what the teacher believes to be the correct answer

x% Indicates that no percentage was estimated by the teacher

Teacher C felt that 20% would say the wrench would be angled down to the moon's surface. This 20% was added to the 50% of the students that this teacher predicted would choose down.

Appendix 5

Inferring Teachers Predictions of Student Grouped Responses: Question #2

In question #2, teachers were asked to predict the percentages of students choosing a force directed upwards, downwards or no force when asked the question of the net force acting on the ball thrown upwards, as the ball moved up, reached the top of its flight and then fell downwards.

Student responses were analysed according to groups of responses they chose, resulting in a situation where the teachers predictions for each group of responses had to be inferred. This was accomplished by finding the product of the probabilities assigned to each of the choices in a group. For example, consider the following prediction of student responses:

1. Force on the ball moving upwards:

   70% upwards, 30% no force, 0% downwards.

2. Force on the ball while at the top:

   0% upwards, 90% no force, 10% downwards.

3. Force on the ball moving downwards:

   0% upwards, 10% no force, 90% downwards.

The following probability for different groupings could be obtained:

a. Up, No, No .... Probability is 70% x 90% x 10% = 6.3%

b. Up, No, Down .. Probability is 70% x 90% x 90% = 56.7%

In the above manner, the probabilities for each of the 27 possible groupings were inferred.

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